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Environmental Emissions of the Stoker Fired Steam Generators

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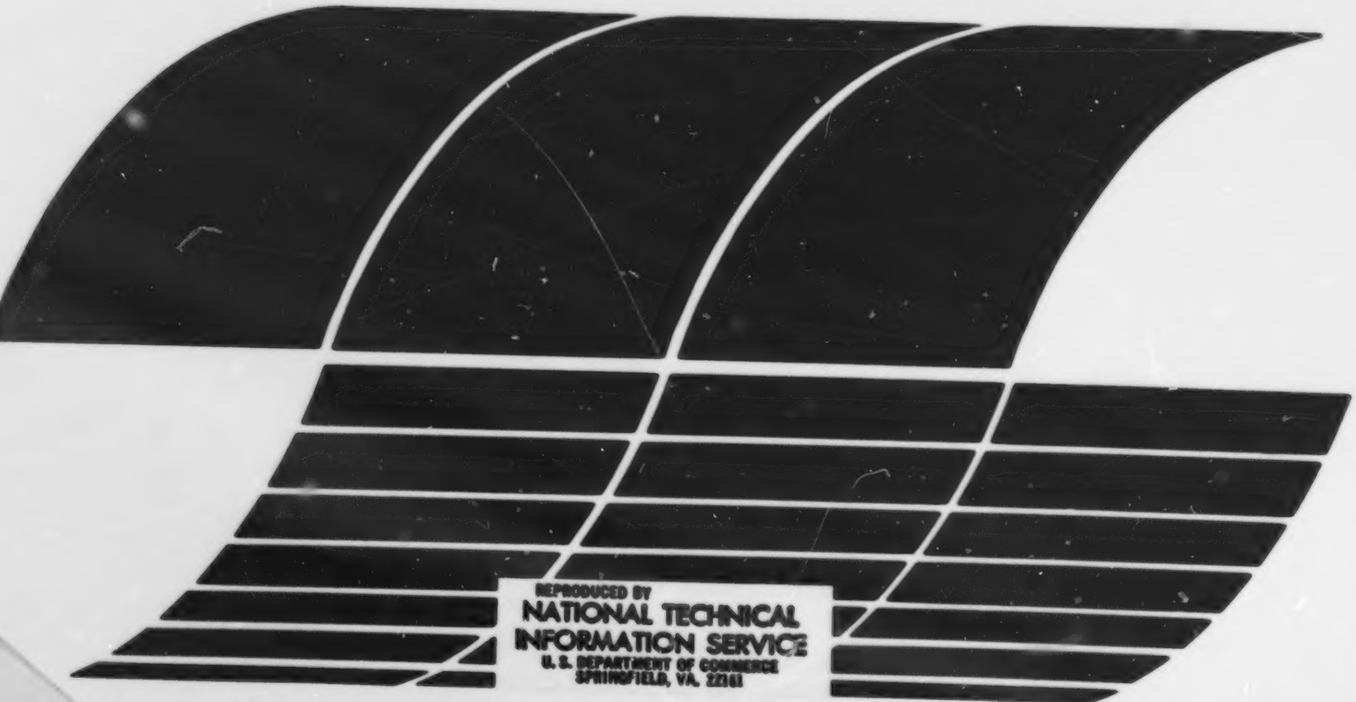

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16. ABSTRACT

This report describes the results of the tests of environmental emissions from the traveling grate stoker boilers at Ames, Iowa. All input and output streams associated with operation of these steam generating units have been sampled. Characterization of fuel (coal and process refuse), ash and stack effluents has been accomplished. Statistical analysis of the data is also included.

Particulate emissions either increased or remained the same with increasing RDF depending on boiler load. NO_x and sulfur emissions decreased and chloride emissions increased with increasing percent RDF. Formaldehyde, cyanide, and phosphate emissions were quite variable with no clear trends of emissions as a function of percent RDF burned. Many of the organic compounds were below the laboratory detection levels, and no comparison of emissions can be made at this time. For the trace elements in the uncontrolled particulates, there were increases due to burning RDF for only copper and lead.

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EVALUATION OF THE AMES SOLID WASTE RECOVERY SYSTEM
PART III: ENVIRONMENTAL EMISSIONS OF THE STOKER FIRED STEAM GENERATORS

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This study was conducted in cooperation with the City of Ames, Iowa; Ames Laboratory, DOE, Ames, Iowa; Engineering Research Institute and Mechanical Engineering Department, Iowa State University, Ames, Iowa; Midwest Research Institute, Kansas City, Missouri; and the Iowa Department of Environmental Quality, Des Moines, Iowa

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

On August 30, 1975, the first continuous full-scale, solid waste recovery system for the processing and burning of municipal solid waste as a supplementary fuel for power generation commenced operation in the City of Ames, Iowa. This report provides the results from the study of environmental emissions from the stoker fired steam generators at the City of Ames. It provides basic data on the environmental emissions when burning coal only and mixtures of coal plus refuse derived fuel. The results and/or conclusions of this report may be utilized to determine what changes occur in emissions when changing from burning coal only to coal plus refuse derived fuel. The information contained herein will be of interest to those designers or users who are contemplating or working with a system similar to Ames. Requests for further information regarding emissions of stoker fired steam generators utilizing refuse derived fuel should be directed to the Fuels Technology Branch, IERL, Cincinnati.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

The project entitled "Evaluation of the Ames Solid Waste Recovery System" encompasses such a large scope of work and has generated such a large amount of data that the annual report on year 01 is divided into three parts.

Part I, entitled "Summary of Environmental Emissions. Equipment, Facilities, and Economic Evaluations" provides a summary of the environmental emissions and boiler performance of stoker fired boilers burning refuse derived fuel (RDF) and coal; characterization of the RDF produced by the processing plant; processing plant and equipment performance evaluations; and an economic analysis of the processing plant.

Part II, entitled "Performance of the Stoker Fired Steam Generators" evaluates the thermodynamic and mechanical performance of the stoker boilers while burning RDF as a supplemental fuel with coal.

Part III, entitled "Environmental Emissions of the Stoker Fired Steam Generators" describes the environmental impact of the stoker boiler cofiring operation. The report includes sample analysis of the input and output streams associated with the operation of the stoker fired boilers while burning coal only and coal plus RDF; characterization of the fuel (coal and RDF), ash and stack effluents; and statistical analysis of the data.

The portion of the project covering environmental emissions from the stoker boilers is jointly funded by the Environmental Protection Agency (EPA) and the Department of Energy (DOE). These results are published jointly by both agencies in Part III.

The balance of the project is funded by the EPA and these results are published in Part I and Part II.

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ACKNOWLEDGMENTS

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The EPA sponsored portion of the program was directed by Mr. Carlton C. Wiles of the Municipal Environmental Research Laboratory, Solid and Hazardous Waste Research Division, Office of Research and Development and Mr. Robert Olexsey, Industrial Environmental Research Laboratory, Cincinnati, Ohio, Office of Energy, Minerals, and Industry. The ERDA sponsored portion of this study was directed by Mr. Robert L. Butenhoff, Physical and Technical Programs, Division of Biomedical and Environmental Research.

The Engineering Research Institute Of Iowa State University was responsible for the environmental sampling, and the preparation of this report. The Ames Laboratory, ERDA was responsible for the major portion of the sample analysis. Midwest Research Institute, was a consultant to the project and aided in development of work plans and methods.

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SECTION 1

INTRODUCTION

The Ames Solid Waste Recovery System is a continuously operating system that is processing municipal solid waste (MSW) for use as a supplemental fuel in the existing steam generators of the Ames Municipal Power Plant. The purpose of this report is to present results of the investigations of the environmental effects of using solid waste as a supplemental fuel. This evaluation is a major research program funded by the Environmental Protection Agency (EPA), the Energy Research and Development Administration (ERDA, now DOE) with earlier additional participation by the American Public Power Association (APPA). This project is being performed jointly by the City of Ames, Iowa, Engineering Research Institute and Mechanical Engineering Department of Iowa State University, Ames Laboratory/ERDA, and Midwest Research Institute (MRI).

This report presents the results and conclusions of the first-year environmental emissions investigation on the two stoker-fired steam generator units when using coal and refuse derived fuel (RDF).

Following sections of this report present a statement of the objectives, a summary of results, a description of the boilers, a description of the experimental design and the sampling methods used, and a presentation of the results. The results of the environmental investigations were analyzed statistically. This statistical study is presented in the Appendix.

SECTION 2

OBJECTIVES

The purpose of this study was to characterize the environmental emissions from the stoker fired boilers when a mixture of coal plus RDF was used as fuel compared to coal only. Studies of the emissions were accomplished by measuring the inputs and outputs from the boilers. A brief summary of the environmental investigations is given below.

1. Sample and characterize the fuel used in the steam generators
    - Coal
    - Processed solid waste
2. Sample and characterize the effluents from the steam generating units
    - a. Solids
        - Study of the particulates in the flue gas for quantity, size distribution, and composition. Testing conducted both before and after the cyclone dust collector.
        - Analysis of bottom ash.
        - Analysis for possible carcinogens in particulates.
    - b. Gases
        - Analysis for SO_x, NO_x, chlorides, organic acids, aldehydes and ketones, cyanide, phosphate, mercury, arsenic, selenium, beryllium, and HC.
        - Identification and analysis of heavy organics in the stack gases.

SECTION 3

SUMMARY OF RESULTS

In coal plus RDF firing applications, there are a variety of air pollution control devices that could be used, such as multiple cyclones, scrubbers and electrostatic precipitators, and therefore, the change in emissions due to burning RDF is of great interest to the designer of future refuse burning installations. The following discussion presents a summary of the emissions due to burning coal only and to burning coal plus RDF.

Both uncontrolled particulate emissions before the particulate collector and stack particulate emissions to the atmosphere did not have clear overall trends as a function of RDF heat input. Particulate emissions either increased or stayed the same with percent RDF, depending on boiler unit and boiler load. Particulate collector efficiency initially increased with increasing percent RDF, then decreased with additional RDF input. The particulate collectors were cyclone separators (multiclones) whose efficiency is a function of such factors as particulate concentration, gas flow rate, and particle size and density. No particulate sizing was done before the particulate collector and the reasons for the changes in collector efficiency are not completely understood at this time. Future tests are planned to include particulate sizing before as well as after the collector, which will allow a better understanding of the changes in collector efficiency.

NO_x and sulfur emissions both have trends of decreasing emissions with increased percent RDF. During these tests, boiler No. 5 used Iowa coal only. Boiler No. 6 used a mixture of one-half Iowa and one-half Wyoming coal. Wyoming coal is lower in sulfur content than Iowa coal, and thus, sulfur emissions for boiler No. 6 are lower, and the effect of RDF is not as pronounced.

Chloride emissions increased with increasing percent RDF for all boiler loads. Chloride emissions were substantially lower for coal only than for coal plus RDF, and therefore, these emissions appear to be a function of the chlorine in the RDF.

Formaldehyde, cyanide, and phosphate emissions were quite variable, with no clear trends of emissions as a function of percent RDF. Emissions at 20% RDF were either lower, or only slightly higher than the coal only emissions. The major exception being cyanide emissions from boiler No. 6 which showed a relatively sharper increase in emissions at 20% RDF than for the other test conditions. However, at 50% RDF, the increases and decreases from the 20% RDF test condition were variable enough to make it difficult to establish a trend based on percent RDF.

No significant hydrocarbon emissions in the C_1 to C_5 range have been found to date. Results from the organic acids analysis and the mercury train are not yet available. Many of the heavy organic compounds in the stack emissions analyzed were below the laboratory detection level and the majority of the organics found were in the stack gases and not in particulate form. These data are the results of only two stack samples performed to assess the potential presence of such compounds. Therefore, no comparisons of emissions as a function of percent RDF can be made at this time.

RDF in combination with coal was successfully fired in the stoker boilers with some difficulty but with no major problems. The maximum RDF firing rate was 50% of the heat input to the boiler supplied by RDF. There was no significant direct effect of burning RDF on the measured boiler thermal efficiency. There was no significant difference in the percent of the heat input leaving as combustibles in the ash, the average being approximately 5% for both coal and RDF. The RDF pneumatic feeders and the additional overfire air required to burn RDF increased the secondary air (excess air) supplied. The increase in excess air required to burn RDF reduced the boiler thermal efficiency. There was general consensus among the boiler operators that more combustion air through the grate is necessary when firing RDF to prevent slagging and to maintain a proper fire bed.

Ultimate fouling of the superheater section of boiler No. 5 was experienced. Calculation of the fuel fouling index correlates with this behavior. The most significant influence is the higher sodium content of RDF which has a detrimental effect on the fouling index. Soot blowers will be installed to reduce this fouling behavior. In addition, an alternate method of RDF injection might reduce this effect.

At most boiler loads, bottom ash tended to increase somewhat and fly ash tended to decrease with increasing percent RDF.

Ash fusion temperatures of RDF are typically 60 to 100°C lower than for coal. However, no specific correlation of boiler performance to ash fusion temperatures has been determined.

SECTION 4

DESCRIPTION OF THE STEAM GENERATING UNITS

At the City of Ames Municipal Power Plant the two existing spreader return traveling grate stoker fired boilers (Nos. 5 and 6) have been modified to burn RDF as a supplemental fuel with coal. The RDF is prepared in a nominal 136 Mg/day refuse processing plant adjacent to the power plant. The processing plant incorporates two stages of shredding, ferrous and nonferrous metal recovery, and an air density separator. RDF is pneumatically conveyed from the processing plant to a 454-Mg storage bin. RDF is conveyed to the boilers via a pneumatic transport system.

The characteristics of the stoker boilers are summarized in Table 1. These boilers were installed in the 1950s, and use cyclone collectors (multiclones) for particulate removal from the exhaust gas to the atmosphere. Both are traveling grate spreader stokers. Boiler No. 5 was built by Riley and boiler No. 6 was built by Union Iron Works. Figures 1, 2, and 3 are cross-sectional views of the boilers. In both boilers coal is discharged into the boiler by a coal distributor. RDF is fed into the boiler by a pneumatic conveying system (not shown). The RDF entry point is adjacent to the coal distributor.

TABLE 1. CHARACTERISTICS OF AMES MUNICIPAL POWER PLANT STEAM GENERATORS

Unit	5	6
Manufacturer	Riley	Union Iron Works
Installation Date	1951	1958
Pressure/Temperature		
kPa/°C	4,895/441	4,998/441
(PSI/°F)	(710/825)	(725/825)
Nominal Steam Output Capacity		
kg/hr	43,091	56,699
(lb/hr)	(95,000)	(125,000)
Coal Firing Equipment	Spreader Stoker Traveling Grate	Spreader Stoker Traveling Grate
Furnace Pressure	Balanced Draft	Balanced Draft
Dust Collection Equipment	Western Multiple Cyclone	American Multiple Cyclone
Stack Height, m (ft)	61 (200)	61 (200)
Heat Input at Nominal Capacity		
MJ/hr	154	202
(BTU x 10^6/hr)	(146)	(191)

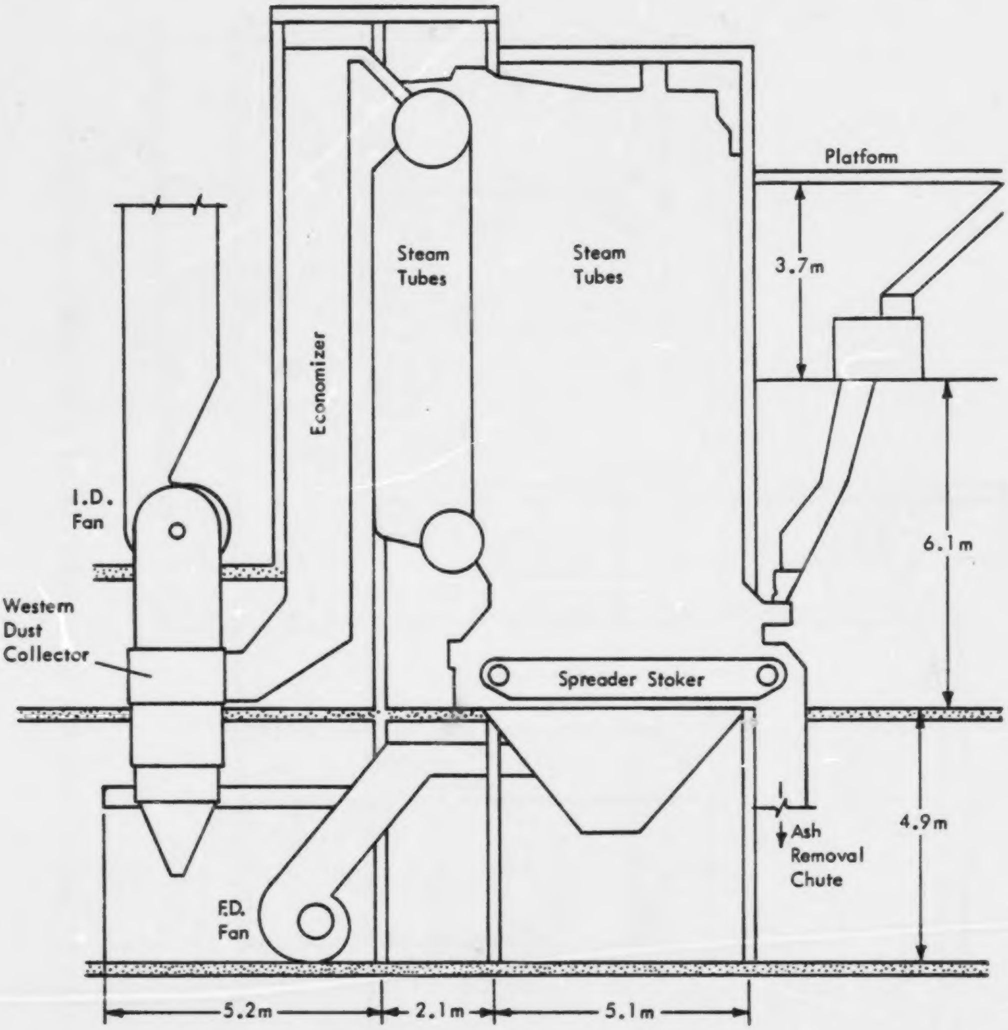

Platform
Steam Tubes
Steam Tubes
3.7m
Economizer
I.D. Fan
6.1m
Western Dust Collector
Spreader Stoker
Ash Removal Chute
4.9m
F.D. Fan
5.2m
2.1m
5.1m

Figure 1. Cross sectional view of boiler unit No. 5.

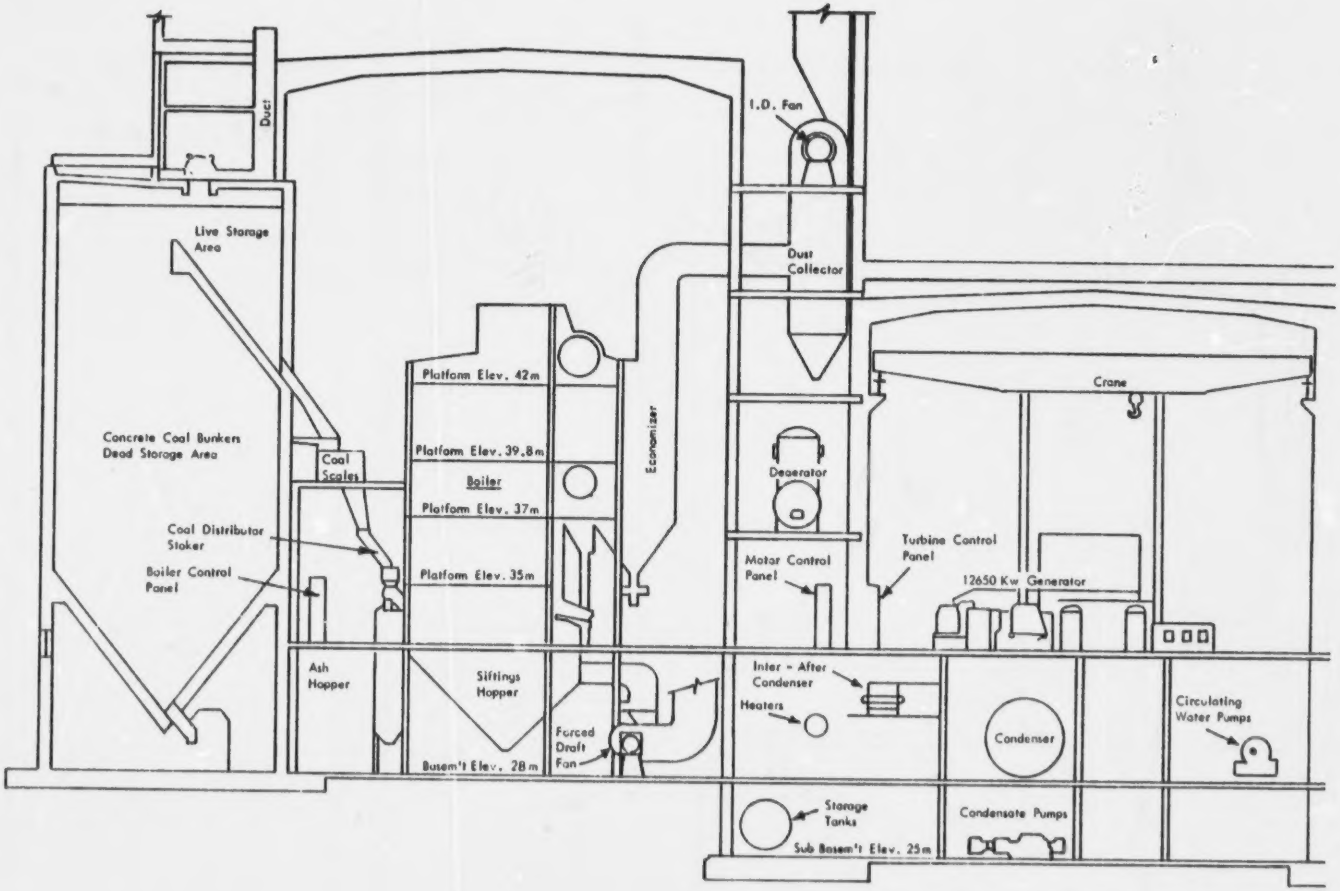

Duct
Live Storage Area
Concrete Coal Bunkers Dead Storage Area
Coal Scales
Coal Distributor Stoker
Boiler Control Panel
Ash Hopper
Platform Elev. 42m
Platform Elev. 39.8m
Boiler
Platform Elev. 37m
Platform Elev. 35m
Siftings Hopper
Basem't Elev. 28m
Economizer
Forced Draft Fan
I.D. Fan
Dust Collector
Deaerator
Motor Control Panel
Inter - After Condenser
Heaters
Storage Tanks
Sub Basem't Elev. 25m
Crane
Turbine Control Panel
12650 Kw Generator
Condenser
Condensate Pumps
Circulating Water Pumps

Figure 2. Elevator view of boiler unit No. 6 and associated power plant apparatus.

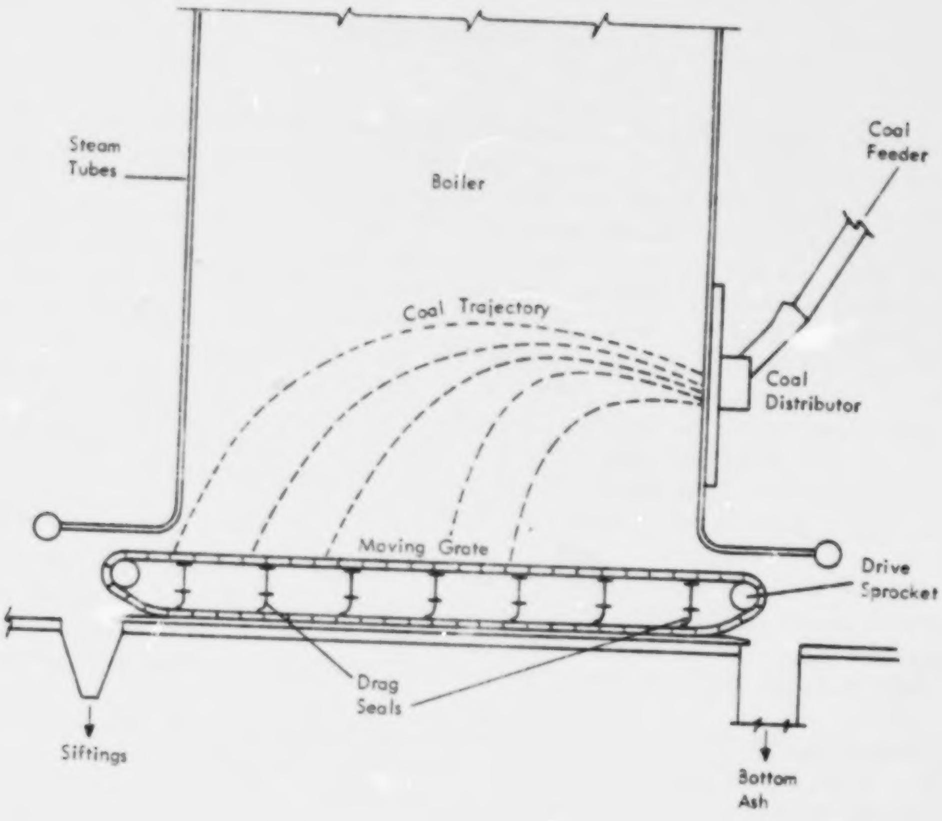

Steam Tubes
Boiler
Coal Feeder
Coal Trajectory
Coal Distributor
Moving Grate
Drive Sprocket
Drag Seals
Siftings
Bottom Ash

Figure 3. Cross sectional view of boiler unit No. 6.

SECTION 5

EXPERIMENTAL DESIGN

In this study, it was determined that two major factors could be controlled at various levels. These factors were the load based on steam flow and the amount of RDF based on heat energy input to the boiler. The levels of these factors were chosen to be 60, 80, and 100% nominal load and 0, 20 and 50% RDF. To obtain sufficient data for statistical analysis, a factorial experimental design with three replications was devised for each boiler as summarized in Table 2. Thus, for boiler unit No. 5 the statistical design is a 3 x 3 x 3 full factorial experiment with 27 runs needed to fill the data matrix of this experiment. In addition, testing of two different size (and design) traveling grate stoker fired boilers (unit Nos. 5 and 6) was accomplished at one load setting (80%) to obtain a relative size comparison for all emission data at a given fixed load. The tests accomplished to date are shown in the data matrix format of Table 3.

To satisfy the objectives of the environmental emissions study, all appropriate input and output streams associated with the operation of steam generating unit Nos. 5 and 6 were sampled. A block diagram showing the sample locations in both entering and leaving streams is given in Figure 4.

Sampling, physical characterization, and chemical element analysis were performed on input fuels, ash, and particulate effluent. Size distributions of the particulate effluent were also determined. In addition, gaseous effluents were sampled and characterized. These gaseous species include oxides of nitrogen (NO_x), oxides of sulfur (SO_x), excess air or oxygen, carbon dioxide, aldehydes and ketones, chlorides, organic acids, mercury, and several others. Each of these items was sampled on a regular basis according to the test summary of environmental sampling shown in Table 3. Heavy organic species, unburned hydrocarbons, and nitrous oxide were sampled on an intermittent basis as man power, instrumentation, and equipment would allow.

TABLE 2. SUMMARY OF FACTORIAL EXPERIMENTAL DESIGN

Stoker Boiler No. 5 Coal Used: Iowa			
% Load % RDF	60	80	100
0	4A, 4B 20 21[a] 36	5 16 17	11 31[b] 32[b]
20	8 9A, 9B 33	6 12 13	7 14 19
50	1 34 35	2 10 15	3 18 [c]

Stoker Boiler No. 6 Coal Used: Mixture of 50% Iowa, 50% Wyoming	
% Load % RDF	80[d]
0	24 29 30
20	25 26 27
50	22 23 28

---

[a] Test 21 conducted while pulling ash from boiler to determine any change in performance and/or emissions due to ash removal.

[b] Bottom ash not weighed because of ash removal difficulties (slagging in boiler and clinkering of ash).

[c] Boiler No. 5 cannot operate at 100% steam load and 50% RDF without severe ash problems due to lack of excess air. Therefore, the third test in series was not conducted.

[d] Load was changed from the originally planned 100% to 80% steam load to be more typical of capability of boiler and air supply for refuse burning. This change was essential from experience gained during testing of Boiler No. 5.

TABLE 3. TEST SUMMARY OF ENVIRONMENTAL SAMPLING (Check Marks Indicate That an Appropriate Sample Has Been Obtained)

Date	Unit	%Load	Fuel a/	%Refuse	Test Designation	Bottom Ash b/	Collector Ash	Particulate c/			Orsat		NOx		SOx		Aldehydes Ketones		Chlorides Org. Acids		Hg, Be, Se		Heavy Organics		HC & N2O	
								BPC	S	Sizing	BPC	S	BPC	S	BPC	S	BPC	S	BPC	S	BPC	S	BPC	S	BPC	S
6- 8-76	#5	60%	C+RDF	50%	EPA 1	✓	✓	✓	✓		✓	✓		✓		✓	✓		✓		✓					
6-10-76	#5	80%	C+RDF	50%	EPA 2	✓	✓	✓	✓		✓	✓	✓	✓		✓		✓		✓	✓					
6-15-76	#5	100%	C+RDF	50%	EPA 3	✓	✓	✓	✓		✓	✓	✓		✓		✓		✓		✓	✓				
6-17-76	#5 B-R d/	60%	C	0%	EPA 4 d/ A & B	✓✓	✓✓	✓✓	✓✓		✓✓	✓✓	✓✓		✓✓		✓✓		✓✓			✓✓				
6-21-76	#5	80%	C	0%	EPA 5	✓	✓	✓	✓		✓	✓		✓		✓		✓		✓		✓				
6-23-76	#5	80%	C+RDF	20%	EPA 6	✓	✓	✓	✓		✓	✓		✓		✓		✓		✓		✓				
6-25-76	#5	100%	C+RDF	20%	EPA 7	✓	✓	✓	✓		✓	✓		✓		✓		✓		✓		✓		✓		
6-28-76	#5	60%	C+RDF	20%	EPA 8	✓	✓	✓	✓		✓	✓		✓		✓		✓		✓		✓				
6-30-76	#5 B-R d/	60%	C+RDF	20%	EPA 9 e/ A & B	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓		✓✓		✓✓		✓✓		✓✓		✓✓				
7- 2-76	#5	80%	C+RDF	50%	EPA 1	✓	✓	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				
7- 6-76	#5	100%	C	0%	EPA 11	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓		✓		✓
7- 8-76	#5 B-R d/	80%	C+RDF	20%	EPA 12 d/	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				
7- 8-76	#5 B-R d/	80%	C+RDF	20%	EPA 13 d/	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				✓
7-16-76	#5	100%	C+RDF	20%	EPA 14	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				
7-17-76	#5	80%	C+RDF	50%	EPA 15	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				
7-19-76	#5 B-R d/	80%	C	0%	EPA 16 d/	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				✓
7-19-76	#5 B-R d/	80%	C	0%	EPA 17 d/	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				
7-23-76	#5	100%	C+RDF	50%	EPA 18	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				✓
7-24-76	#5	100%	C+RDF	20%	EPA 19 g/	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓	TEST ABORTED - BOILER COULD NOT HOLD LOAD									
8- 2-76	#5 B-R d/	60%	C	0%	EPA 20 d/	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				✓
8- 2-76	#5 B-R d/	60%	C	0%	EPA 21 d,f/	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				✓
7-26-76	#5	60%	C+RDF	50%	EPA 1-Supp.	--	--	--	-	✓	--	-		-		-	TEST ABORTED - RAIN					--				--

TABLE 3. (Concluded)

Date	Unit	%Load	Fuel a/	%Refuse	Test Designation	Bottom Ash b/	Collector Ash	Particulate c/			Orsat		NO_x		SO_x		Aldehydes Ketones		Chlorides Org. Acids		Hg,Be,Se		Heavy Organics		HC & N_2O	
								BPC	S	Sizing	BPC	S	BPC	S	BPC	S	BPC	S	BPC	S	BPC	S	BPC	S	BPC	S
8- 5-76	#6	80%	C+RDF f/	50%	EPA 22	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				✓
8- 6-76	#6	80%	C+RDF	50%	EPA 23	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				✓
8- 9-76	#6	80%	C	0%	EPA 24	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				✓
8-10-76	#6	80%	C+RDF	20%	EPA 25	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				✓
8-11-76	#6	80%	C+RDF	20%	EPA 26	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				✓
8-12-76	#6	80%	C+RDF	20%	EPA 27	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				✓
8-13-76	#6	80%	C+RDF	50%	EPA 28	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				✓
8-16-76	#6	80%	C	0%	EPA 29	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				✓
8-18-76	#6	80%	C	0%	EPA 30	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				✓
8-24-76	#5 B-B d/	100%	C	0%	EPA 31 e/	✓ g/	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				
8-24-76	#5 B-B d/	100%	C	0%	EPA 32 e/	✓ g/	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				
8-25-76	#5	60%	C+RDF	20%	EPA 33	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				
8-26-76	#5 B-B d/	60%	C+RDF	50%	EPA 34 e/	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				
8-26-76	#5 B-B d/	60%	C+RDF	50%	EPA 35 e/	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				
8-27-76	#5	60%	C	0%	EPA 36	✓	✓ wt	✓	✓	✓	✓	✓		✓		✓		✓		✓		✓				

a/ Coal for tests on Boiler No. 5 is Iowa coal; on No. 6, 50% Wyoming and 50% Iowa coal.
b/ Bottom Ash and Collector Ash weighed together after completion of test and removal of ash to ash silo except where special weights are noted.
c/ BPC - Before Particulate Collector; S = Stack; Sizing = Sizing on stack.
d/ B-B indicates back-to-back testing.
e/ Boiler load dropped and test terminated early.
f/ Test conducted while pulling ash to determine if boiler performance and emissions change when ash is pulled.
g/ Bottom ash not weighed due to ash removal difficulties.

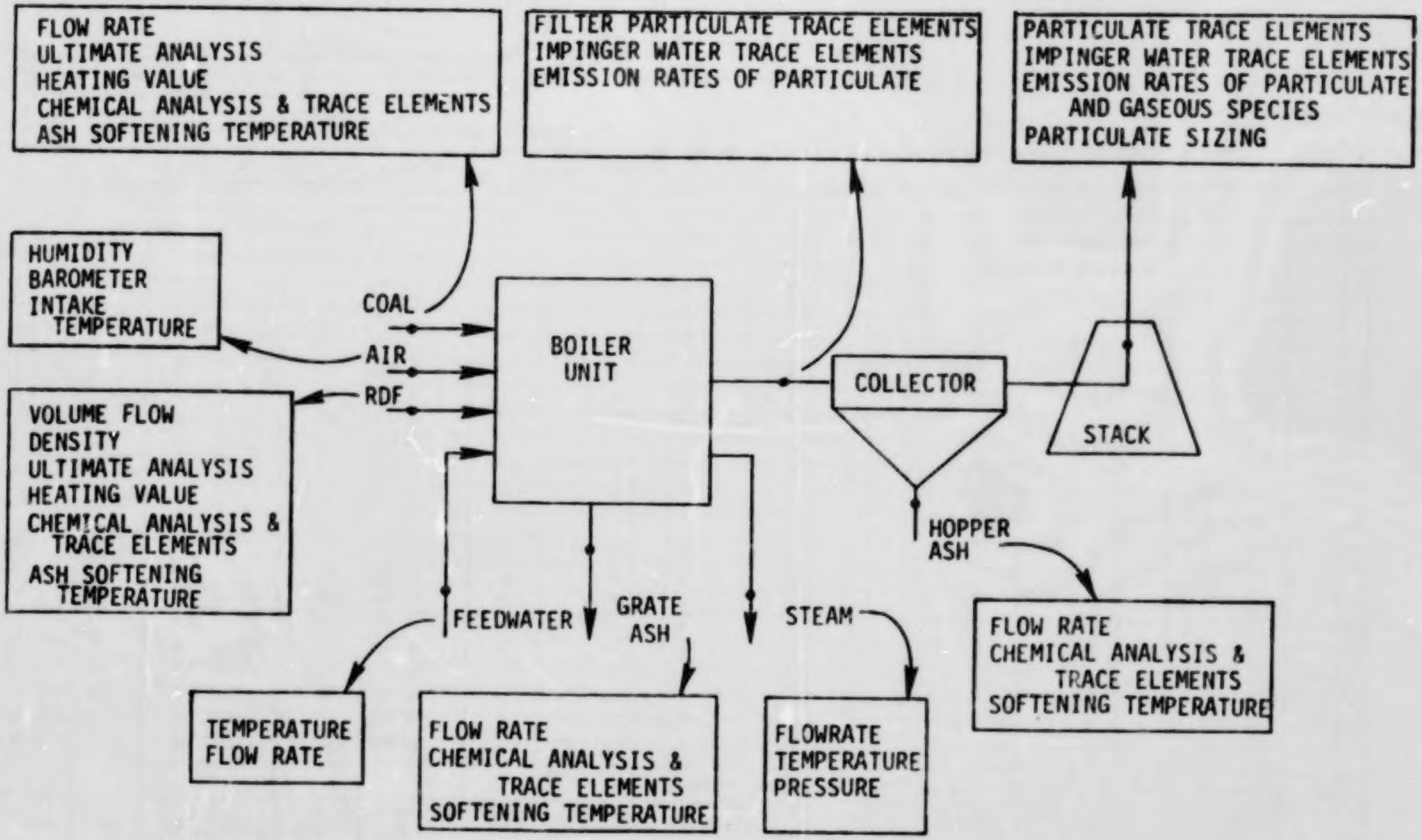

FLOW RATE
ULTIMATE ANALYSIS
HEATING VALUE
CHEMICAL ANALYSIS & TRACE ELEMENTS
ASH SOFTENING TEMPERATURE
FILTER PARTICULATE TRACE ELEMENTS
IMPINGER WATER TRACE ELEMENTS
EMISSION RATES OF PARTICULATE
PARTICULATE TRACE ELEMENTS
IMPINGER WATER TRACE ELEMENTS
EMISSION RATES OF PARTICULATE AND GASEOUS SPECIES
PARTICULATE SIZING
HUMIDITY
BAROMETER
INTAKE TEMPERATURE
COAL
AIR
RDF
BOILER UNIT
COLLECTOR
STACK
VOLUME FLOW
DENSITY
ULTIMATE ANALYSIS
HEATING VALUE
CHEMICAL ANALYSIS & TRACE ELEMENTS
ASH SOFTENING TEMPERATURE
HOPPER ASH
FEEDWATER
GRATE ASH
STEAM
FLOW RATE
CHEMICAL ANALYSIS & TRACE ELEMENTS
SOFTENING TEMPERATURE
TEMPERATURE
FLOW RATE
FLOW RATE
CHEMICAL ANALYSIS & TRACE ELEMENTS
SOFTENING TEMPERATURE
FLOWRATE
TEMPERATURE
PRESSURE

Figure 4. Boiler unit No. 5 and unit No. 6 sampling locations.

SECTION 6

SAMPLING METHODS

GENERAL

During a given test, samples were obtained at all points shown in Figure 4 on a given unit. The input fuel and boiler load were held as constant as possible at their preselected nominal values during a given test. Each test was typically 4 to 5 hr in length if no difficulties were encountered. On some occasions, the test lasted for more than 8 hr. On other occasions, back-to-back tests were accomplished during a given day. The back-to-back tests were also indicated in Table 2.

The input fuel and grate ash were sampled at regular 1-hr intervals throughout the testing period on any given day. These samples were then mixed to yield a composite sample for the given test.

The stack effluents were generally sampled according to EPA prescribed techniques. The preparation of each sampling train included: (a) cleaning the sample train glassware with an appropriate acid wash followed by several distilled water rinses, (b) preparation of chemicals and loading each sample train impinger with the appropriate absorbing solution, (c) weighing and labeling each impinger for each sample train, (d) weighing and loading particulate train filters, (e) checking sample box, control box, and sampling probe for proper operation. Once these checks were accomplished, the sampling train was transported to the test site and prepared for operation as desired.

Leak checks were performed on each sample train from the sampling probe tip both before and after each sample run. No sampling train was operated until it had passed an appropriate leak check from the nozzle tip in the field location. The maximum allowable leak rate was 0.6 liters/min at a sampling train vacuum of 50.8 kPa. A leak rate of 0.6 liters/min was also allowed at a lower vacuum as long as this vacuum level was not exceeded during the test. All sample train leak checks during this study complied with this leak rate criterion. After each experimental run, a leak check was also performed to insure that no leak had developed during the sampling period. The samples were obtained either isokinetically or proportionally as required but only after the calibrations for the dry gas volume flow meter, flow orifice, Pitot tube, sampling nozzle, and temperature sensors on the sampling train had been previously completed.

After sampling, the sampling train impingers and filters were weighed and/or prepared for analysis in an appropriate manner. The impinger chemicals were transferred to clean reagent bottles, the filters were desiccated to dryness before weighing, and the coal, RDF, and ash samples were mixed and ground. All of the samples were then transferred to the various analytical groups of the Ames Laboratory-ERDA for analysis.

The appropriate details of sampling and analysis for the experimental runs of this study are described in the following paragraphs.

INPUT STREAMS

Coal

Coal samples were collected at 1-hr intervals during the experimental runs. These samples were then combined and mixed to form a single test run sample composite for analysis. The samples were prepared for analysis by grinding in a hammer mill. Heating value, ultimate analysis, chemical analysis for elements, and ash softening temperatures were then determined by the techniques indicated in Table 4.

Refuse Derived Fuel (RDF)

Solid waste, RDF, samples were collected at 1-hr intervals during the experimental runs. These samples were then combined and mixed to form a single test run sample composite for analysis. The RDF samples were weighed, heated to 110°C for sterilization, then reweighed to determine the moisture content of the original sample. Samples were prepared for analysis by grinding in a Wiley Mill. Heating value, ultimate analysis, chemical analysis for elements, and ash softening temperatures were then determined by techniques indicated in Table 4.

Air

The air stream entering the boiler unit for purposes of combustion was characterized by measuring the wet bulb temperature, the dry bulb temperature, and the barometric pressure. The wet and dry bulb temperature readings were used to determine the relative humidity by the standard psychometric method.

TABLE 4. ELEMENTS DETERMINED AND ANALYTICAL METHOD USED FOR ANALYSIS OF COAL, REFUSE DERIVED FUEL, AND ASH SAMPLES

Element	X-ray fluorescence[b]	ASTM Method
Aluminum	X	
Arsenic	X	
Calcium	X	
Carbon		D3178
Chromium	X	
Copper	X	
Gallium	X	
Germanium	X	
Hydrogen		D3178
Iron	X	
Lead	X	
Magnesium[a]	X	
Manganese	X	
Nickel	X	
Phosphorus[a]	X	
Potassium[a]	X	
Rubidium	X	
Selenium	X	
Silicon	X	
Sodium[a]	X	
Strontium	X	
Sulfur		D3177
Titanium	X	
Vanadium	X	
Zinc	X	
Ash		D3174
Moisture		D3173
Higher heating value		D2015

[a] Samples were also sent to ACCU-Labs Research, Inc. for analysis by ASTM Method D2795 for these elements.

[b] Additional elements were scanned but not detected by this technique. Detection limits for all elements scanned are given in Table 7.

EXIT STREAMS

Ash

Grate (Bottom) Ash--

Grate ash samples were collected at 1-hr intervals during the experimental runs on boiler unit Nos. 5 or 6. These samples were then combined and mixed to form a single sample composite for analysis. The grate ash sample was prepared for analysis by grinding in a Braun plate-type pulverizer. The resulting powdered samples were analyzed except for heating values, by the techniques indicated in Table 4.

Hopper (Fly) Ash--

Hopper ash samples were collected from the ash hoppers of the mechanical particulate collectors associated with each of the two boiler units. These samples were obtained at the end of each experimental run. Several samples were taken to obtain adequate representation of the hopper ash collected during an experimental run. These samples were then combined and mixed to form a single sample composite for analysis. The hopper ash was prepared for analysis by grinding in a Braun plate-type pulverizer. The resulting powdered samples were analyzed, except for heating values, by the techniques indicated in Table 4.

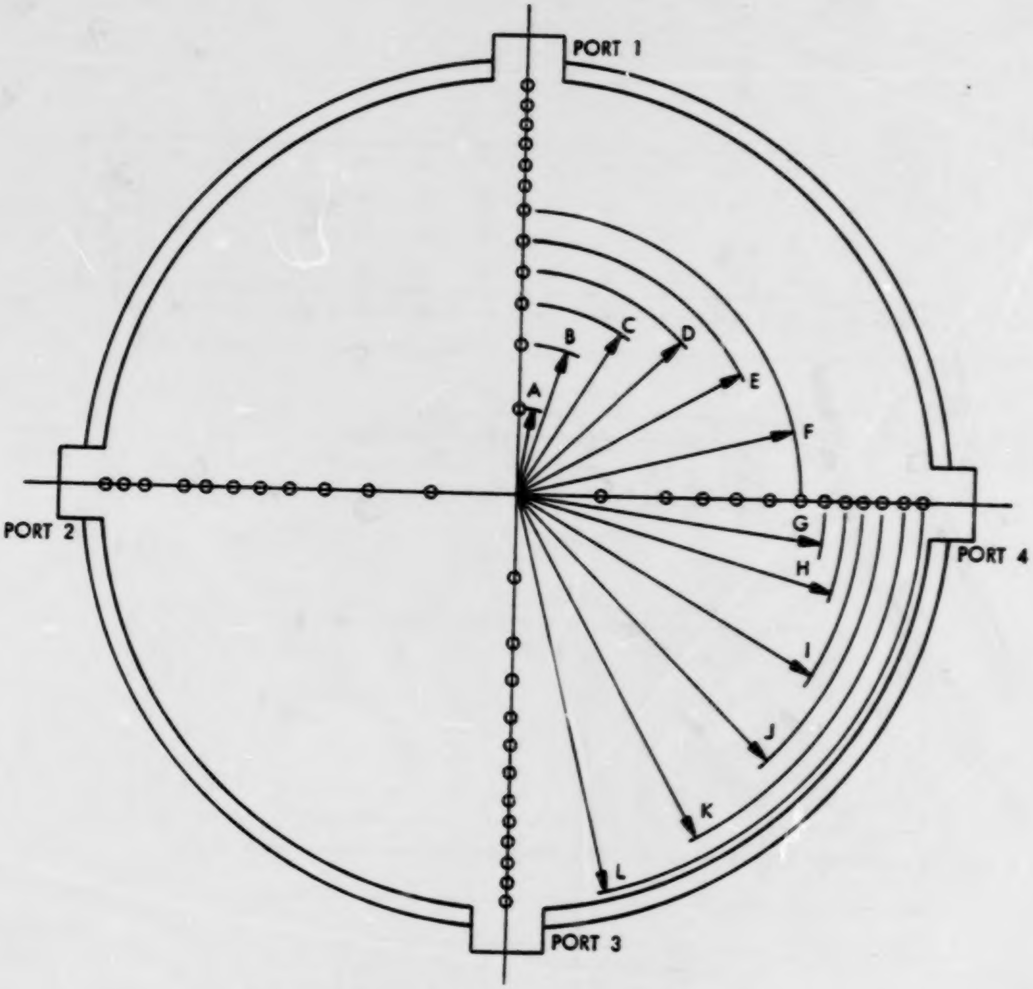
Steam

The boiler load was determined by measuring the steam flow rate generated by the boiler unit. The steam flow integrator reading, the steam temperature and steam pressure were recorded along with feedwater flow rate and feedwater temperature.

Stack Effluents

The stack effluents from boiler unit Nos. 5 and 6 have been obtained by methods prescribed by EPA,[1-3] Carotti and Kaiser,[4] and Shannon.[5]

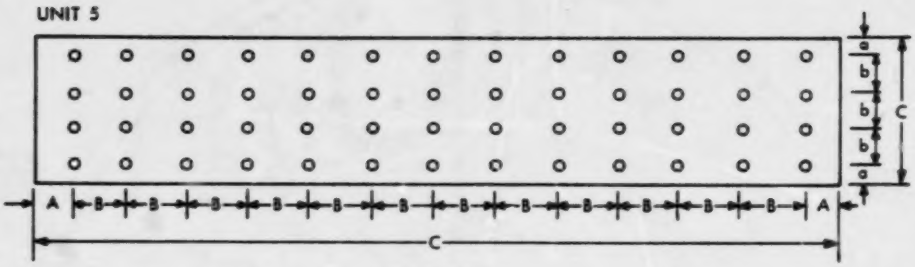
Effluents, such as particulate matter, requiring isokinetic sampling were obtained at 48 prescribed points in the boiler stack cross section as shown in Figure 5. Particulate samples obtained before the mechanical particulate collectors in unit Nos. 5 or 6 were obtained at 52 and 48 prescribed points, respectively, in the direct cross section as shown in Figure 6. Both boiler units exhaust from the individual particulate collectors into the same smoke stack. Thus, when boiler unit No. 5 was being tested, unit No. 6 was not operating and vice versa.


PORT 1
PORT 2
PORT 3
PORT 4
A
B
C
D
E
F
G
H
I
J
K
L

POINT	RADIUS	
	CM	in.
A	32.5	12.79
B	56.4	22.20
C	72.6	28.59
D	86.0	33.86
E	97.5	38.37
F	108.0	42.51

POINT	RADIUS	
	CM	in.
G	117.2	46.15
H	125.8	49.53
I	134.1	52.79
J	141.7	55.80
K	149.1	58.69
L	155.8	61.32

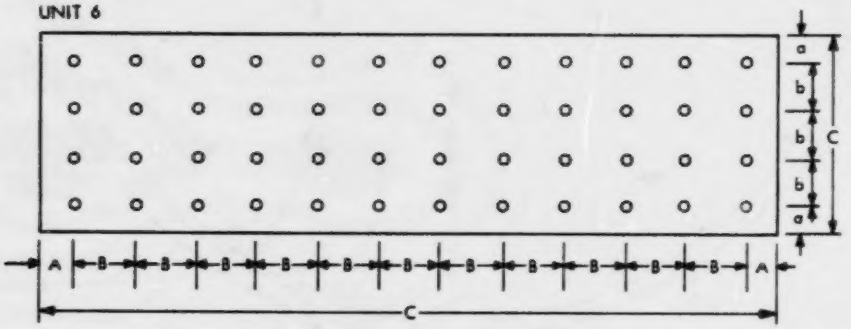
Figure 5. Sampling locations for isokinetic sampling of boiler unit Nos. 5 and 6 exhaust gas stack.



UNIT 5

DIMENSIONS

	CM	in.			CM	in.
A	20.5	8.08		a	12.0	4.75
B	41.0	16.125		b	24.1	9.50
C	533.4	210.0		c	96.5	38.0



UNIT 6

	CM	in.			CM	in.
A	16.5	6.5		a	14.6	5.75
B	33.0	13.0		b	29.2	11.50
C	396	156.0		c	116.8	46.0

Figure 6. Sampling locations for isokinetic sampling of boiler unit Nos. 5 and 6 before the particulate collector.

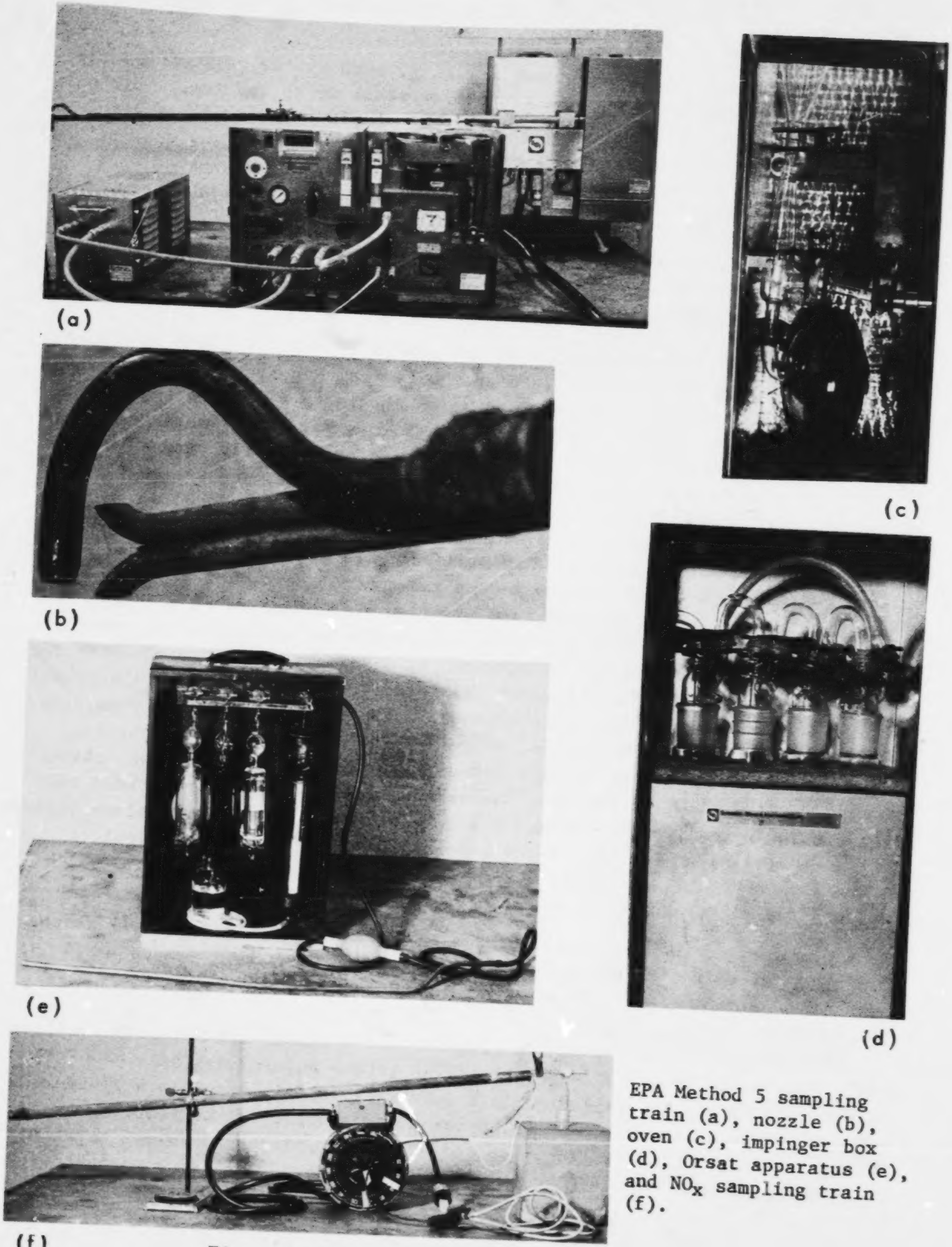
Effluents requiring proportional sampling, such as the gaseous species, were obtained at a single point in the boiler stack cross section. This point usually corresponded to the position where the sampling probe was inserted to its maximum length into the stack. The proportional sampling was accomplished simultaneously with the particulate sampling during any experimental run. Normally, three different sampling trains were operating simultaneously in the stack along with another particulate sampling train located before the particulate collector. The remaining stack porthole was used to obtain grab samples for the Orsat analyses, nitrogen oxides, unburned hydrocarbons, and other miscellaneous gaseous species.

The sampling train configuration was generally that of EPA Method 5, or a modification thereof, as described in the Federal Register[1-3] and shown in Figure 7. The sampling train consists of a sampling probe, sampling box, umbilical cord, and control box as shown in Figure 7a. The sample probe consists of a heated glass liner, a sampling nozzle or probe tip, and an s-type Pitot tube (Figure 7b). The sampling box consists of an oven heated filter and cyclone (Figure 7c) and a set of impingers (Figure 7d) placed in an ice bath and loaded with a variety of chemicals for proper absorption or condensation of the specific interest. The umbilical cord provides vacuum lines and electrical cables between the sample box and control box. The gas flow rate through the train can be metered, and its flow rate adjusted at the control box. It provides electrical energy to the sample box and probe for heating purposes, and it provides for measurement of a variety of temperatures in the sampling system as well as the stack gas velocity. Block diagrams illustrating the various steps and/or measurements necessary to ascertain the particulate emissions, gaseous emissions, and elemental analysis of particulates collected on the filter in the EPA Method 5 sampling train are shown, respectively, in Figures 8, 9, and 10. The various gaseous samples have been collected using a modified EPA Method 5 sampling train. The modifications include a glass wool plug in the tip of the sampling probe to prevent particulate matter from entering, and a section of glass tubing called a "bypass" which replaces the filter and cyclone assembly in the oven of the sampling train.

A summary of the chemicals in each sample train impinger as well as the flow rates used in this study are given in Tables 5 and 6.

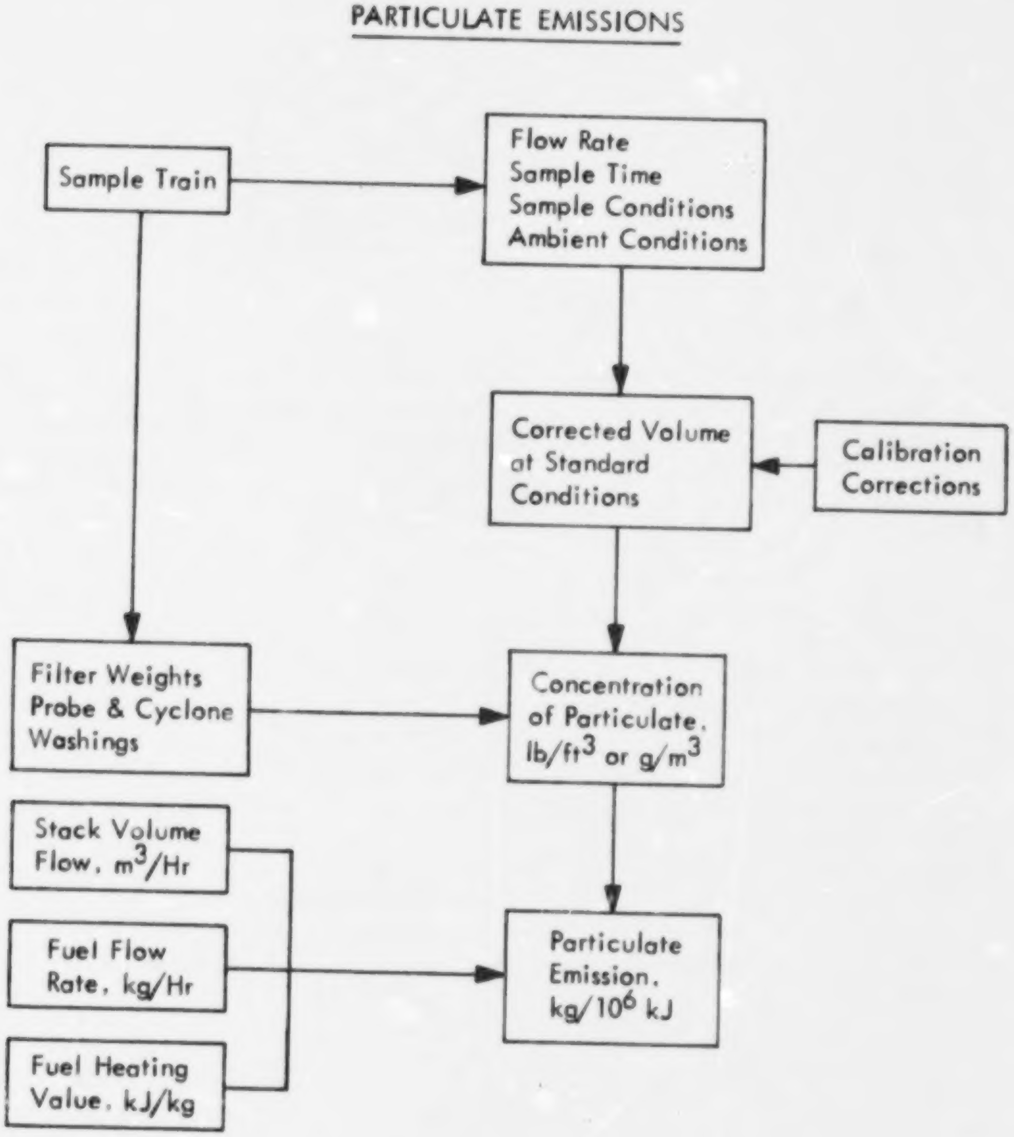
Particulates--

The particulate effluent has been collected by the EPA Method 5 sampling train previously described and as outlined in the Federal Register.[1,2] The particulate matter was collected on a quartz fiber filter and in a glass cyclone preceding the filter. The particulate trapped in the sampling probe during an experimental run was also added to the cyclone and filter catch to yield a measurement of the particulate effluent leaving the smoke stack.



EPA Method 5 sampling train (a), nozzle (b), oven (c), impinger box (d), Orsat apparatus (e), and NO_x sampling train (f).

Figure 7. Photographs of sampling equipment.



PARTICULATE EMISSIONS

Sample Train
Flow Rate
Sample Time
Sample Conditions
Ambient Conditions
Corrected Volume at Standard Conditions
Calibration Corrections
Filter Weights Probe & Cyclone Washings
Concentration of Particulate, lb/ft3 or g/m3
Stack Volume Flow, m3/Hr
Fuel Flow Rate, kg/Hr
Fuel Heating Value, kJ/kg
Particulate Emission, kg/10⁶ kJ

Figure 8. Block diagram of particulate emissions data flow.

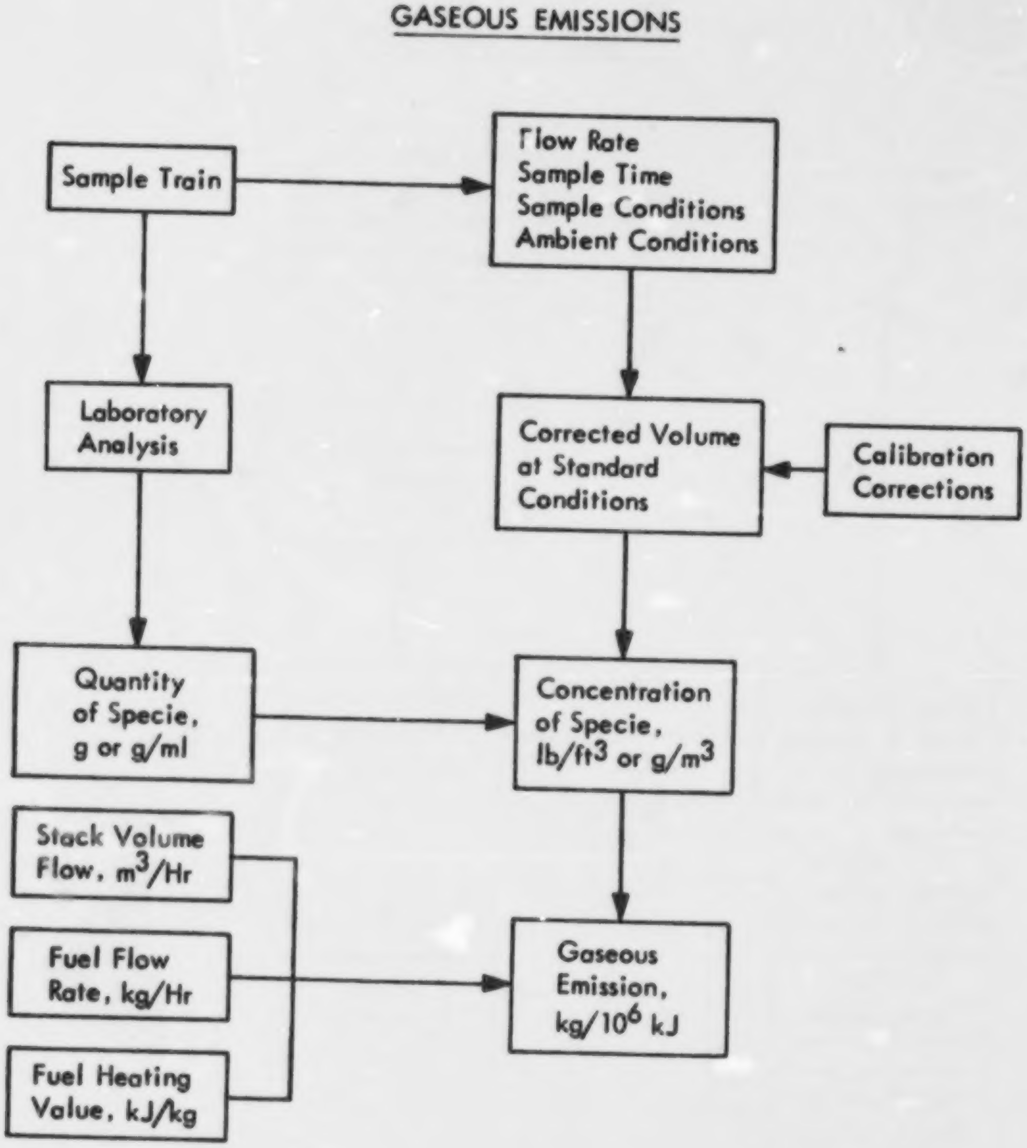

GASEOUS EMISSIONS
Sample Train
Flow Rate
Sample Time
Sample Conditions
Ambient Conditions
Laboratory Analysis
Corrected Volume at Standard Conditions
Calibration Corrections
Quantity of Specie, g or g/ml
Concentration of Specie, lb/ft3 or g/m3
Stack Volume Flow, m3/Hr
Fuel Flow Rate, kg/Hr
Fuel Heating Value, kJ/kg
Gaseous Emission, kg/106 kJ

Figure 9. Block diagram of gaseous emissions data flow.

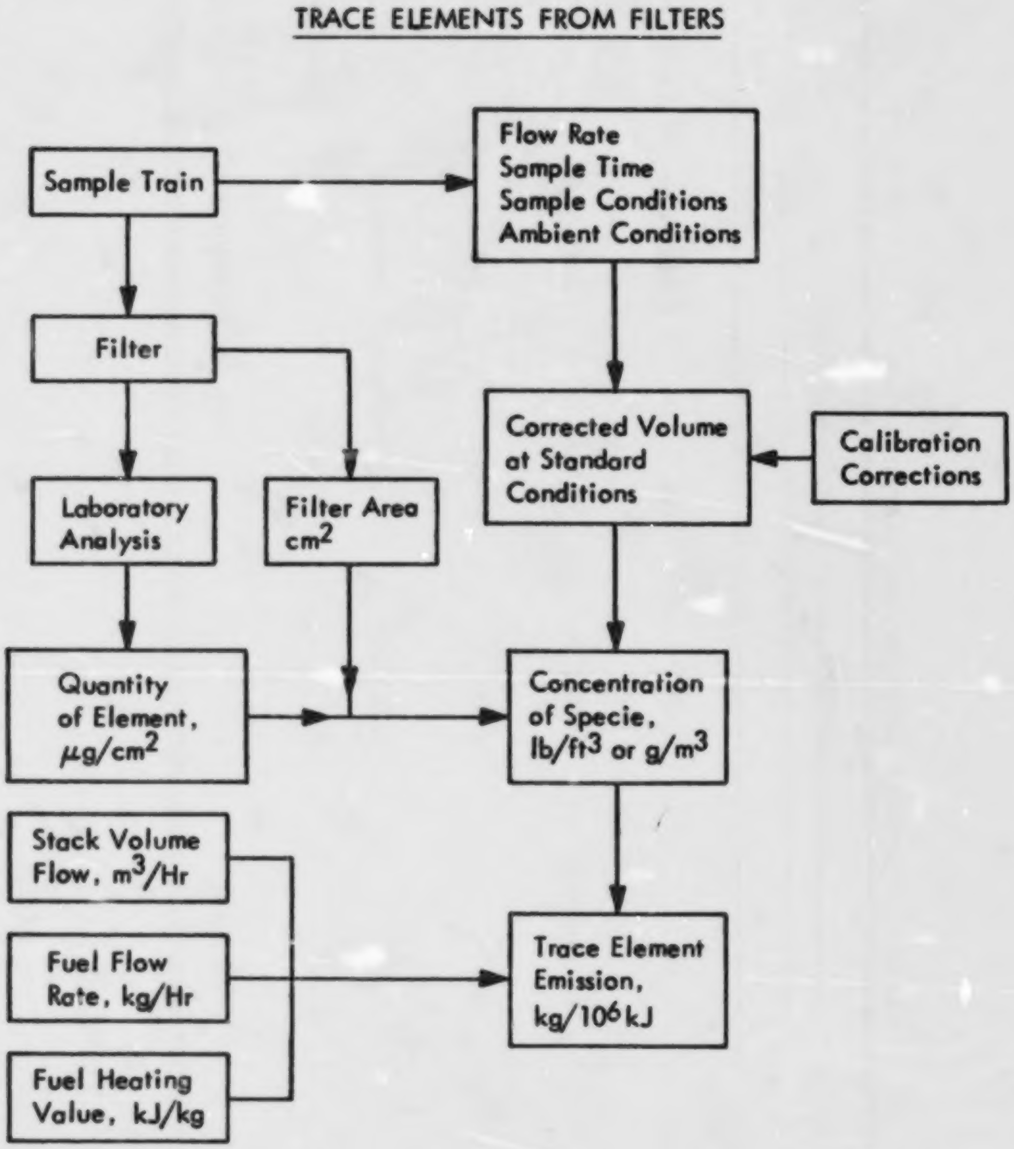

TRACE ELEMENTS FROM FILTERS
Sample Train
Flow Rate
Sample Time
Sample Conditions
Ambient Conditions
Filter
Corrected Volume at Standard Conditions
Calibration Corrections
Laboratory Analysis
Filter Area cm2
Quantity of Element, μg/cm2
Concentration of Specie, lb/ft3 or g/m3
Stack Volume Flow, m3/Hr
Fuel Flow Rate, kg/Hr
Fuel Heating Value, kJ/kg
Trace Element Emission, kg/106 kJ

Figure 10. Block diagram of trace element from filters data flow.

TABLE 5. IMPINGER SOLUTIONS FOR SAMPLE TRAINS

Sample train	Solution in each impinger				Flow rate
	Impinger No.				
	1	2	3	4	
Particulate (EPA method No. 5)	H_2O[a]	H_2O[a]	Dry	Drierite	Isokinetic
Oxides of sulfur (EPA method No. 6)	Isopropanol	3% H_2O_2	3% H_2O_2	Drierite	Proportional at 8 ℓ/min
Aldehydes and Keytones[b]	Dry	$NaHSO_3$	$NaHSO_3$	Drierite	Proportional at 3 ℓ/min
Chlorides and organic acids[b]	H_2O[a]	1.5N NaOH	1.5N NaOH	Drierite	Proportional at 20 ℓ/min
Andersen[b]	H_2O[a]	Dry	Drierite	--	Isokinetic
Mercury vapor[b] "midget"	10% K_2CO_3	ICl	ICl	Drierite	Proportional at 1 ℓ/min

[a] Double distilled water.
[b] EPA method No. 5 modified.

TABLE 6. IMPINGER SOLUTIONS FOR MERCURY VAPOR SAMPLE TRAINS

EPA test No.	Solution in each impinger						
	Impinger No.						
	1	2	3	4	5	6	7
1	$0.5\underline{N}$ HNO_3	$0.5\underline{N}$ KOH	Dry				
2	$0.5\underline{N}$ HNO_3	$0.5\underline{N}$ KOH	Dry	Drierite			
3[a]	KMnO	$0.5\underline{N}$ KOH	Dry	Drierite			
3[b]	$0.5\underline{N}$ HNO_3	$0.5\underline{N}$ KOH	Dry	Drierite			
4A	ICl	ICl	ICl	Drierite	Ascarite		
4B	ICl	ICl	ICl	Drierite	Ascarite		
5	ICl	ICl	ICl	Drierite	Ascarite		
6	ICl	ICl	ICl	Drierite	Ascarite		
7	ICl	ICl	ICl	Drierite	Ascarite		Ascarite
8[a]	K_2CO_3	K_2CO_3	ICl	ICl	ICl	Drierite	
8[a]	ICl	ICl	ICl	Drierite	Ascarite		
9A	K_2CO_3	ICl	ICl	ICl	Drierite		
9B	K_2CO_3	ICl	K_2CO_3	ICl	Drierite/ Ascarite	Ascarite	
10	K_2CO_3	ICl	ICl	ICl	Drierite	Drierite/ Ascarite	
11	K_2CO_3	ICl	ICl	ICl	Drierite	Drierite	
12	K_2CO_3	ICl	ICl	ICl	Drierite	Drierite	
13	K_2CO_3	ICl	ICl	ICl	Drierite	Drierite	
14	K_2CO_3	ICl	ICl	ICl	Drierite	Drierite	
15	K_2CO_3	ICl	ICl	ICl	Drierite	Drierite	
16[b]	Dry	HNO_3	KOH	Drierite			
↓							
36	Dry	HNO_3	KOH	Drierite			

[a] Two sampling trains were used for Test Nos. 3 and 8.

[b] Same solution was in all impingers for Test Nos. 16 through 36.

Flow Rate: Proportional at 1 ℓ/min.

The sample train flow rate was adjusted to a value that would allow isokinetic sampling at each of the 48 points in the stack cross section. Sampling was generally performed for a time period of 3 min at each of the 48 points although some experimental runs were accomplished at 5 min/point. A pretest velocity measurement (presurvey) was usually performed before any test run so that isokinetic sampling could be adjusted on the sample train.

In addition to the determination of the mass of particulate effluent, the particulates on the filters were analyzed for elemental composition by the x-ray fluorescence technique. The list of elements scanned by this technique is included in Table 7.

The loaded filters from the EPA Method 5 sampling train were found to contain large amounts of sulfuric acid (H_2SO_4). In order to analyze trace element concentration on the filter, it was necessary to first fix the H_2SO_4 as $(NH_4)_2SO_4$ by pretreating the filter with NH_4OH fumes. Elemental composition was then determined by x-ray fluorescence.

Trace elements in the particulate effluent sampling train impingers were determined by an Inductively Coupled Plasma Analytical System (ICP).6/ Trace element analysis of impinger solutions from other sampling trains was also accomplished by this technique. The list of elements scanned by this technique is included in Table 8.

Particulate Sizing--

Sizing of stack particulate emissions for boiler unit Nos. 5 and 6 was performed in situ using an Andersen 2000 Inc. Mark III Stack Sampling Head. The Andersen sizer is a cascade impactor that uses inertial separation to separate particles by aerodynamic size. The Andersen sampler could not be inserted in the stack because the stack sampling ports were too small. Instead, the Andersen sampler was used in conjunction with an EPA Method 5 sampling train. The probe was heated to 121° C and the sampler was secured in the oven of the sampling box in place of the Method 5 filter and cyclone assembly. The oven temperature was maintained at 121° C ± 14° C. Specifically, a Misco sampling box and control unit was used. Figure 11 shows the placement of the sampler in the oven. Stack port 3, the southwest port, was used for all sizing tests.

Sampling of particles necessitates isokinetic sampling, therefore, the use of an EPA Method 5 probe was felt to be the best way to achieve this. Measurements of stack temperature and dynamic pressure as well as dry gas meter readings and meter temperatures were taken throughout the test duration and adjustments in flow made to maintain an isokinetic flow rate. Since all sampling was performed at one location for a total time of not more than 20 min, very little variation in flow rate resulted. Short sampling times were used because of the high particulate loading of the sampler stages.

TABLE 7. DETECTION LIMITS OF ELEMENTS SCANNED BY X-RAY FLUORESCENCE (XRF)

Elements	Ash samples WPPM[f]	Coal samples WPPM	Stack filters µg/cm^2	Refuse derived fuel WPPM
Aluminum	10,000	5,000	300[a]	61,000
Arsenic	10	2	0.2	61
Beryllium	5	2	0.2	30.5
Calcium	800	400	40	4,880
Chlorine	3,000	1,000	100	18,300
Chromium	100	20	0.5	610
Cobalt	30	20	0.4[b]	183
Copper	20	10	0.2	122
Gallium	10	2	0.4[c]	61
Germanium	10	2	0.4	61
Iron	50	20	0.4	305
Lead	25	10	1.0	152
Manganese	70	20	0.5	427
Nickel	20	10	0.3	122
Phosphorus	8000	4,000	250	48,800
Potassium	1,000	500	50	6,100
Rubidium	5	1	0.1	30.5
Scandium	600	300	20	3,660
Selenium	5	2	0.2[c]	30.5
Silicon	8,000	4,000	250	48,800
Strontium	5	1	0.1	30.5
Sulfur	5,000	3,000	200	30,500
Titanium	500	200	5[d]	3,050
Vanadium	200	50	1[e]	1,220
Yttrium	5	1	0.1	30.5
Zinc	20	5	0.2	122
Zirconium	5	1	0.1	30.5

[a] Lead interferes at any concentration

[b] Iron interferes at moderate concentration.

[c] Lead interferes at high concentration.

[d] Iron interferes at high concentration.

[e] Titanium interferes at moderate concentration.

[f] Parts per million on a weight basis.

TABLE 8. DETECTION LIMITS OF ELEMENTS SCANNED BY INDUCTIVELY COUPLED PLASMA

Element	Detection limit µg/ml	Element	Detection limit µg/ml	Element	Detection limit µg/ml
Aluminum	0.009	Lead	0.02	Zinc	0.0006
Antimony	0.03	Magnesium	0.004		
Arsenic	0.04	Manganese	0.0002		
Barium	0.001	Mercury	0.03		
Beryllium	0.0002	Molybdenum	0.03		
Bismuth	0.02	Nickel	0.009		
Boron	0.002	Phosphorus	0.5		
Cadmium	0.001	Selenium	0.02		
Calcium	0.008	Silicon	0.07		
Chromium	0.002	Strontium	0.008		
Cobalt	0.002	Thallium	0.06		
Copper	0.0009	Tin	0.08		
Gallium	0.02	Titanium	0.006		
Germanium	0.1	Vanadium	0.002		
Iron	0.005	Yttrium	0.007		

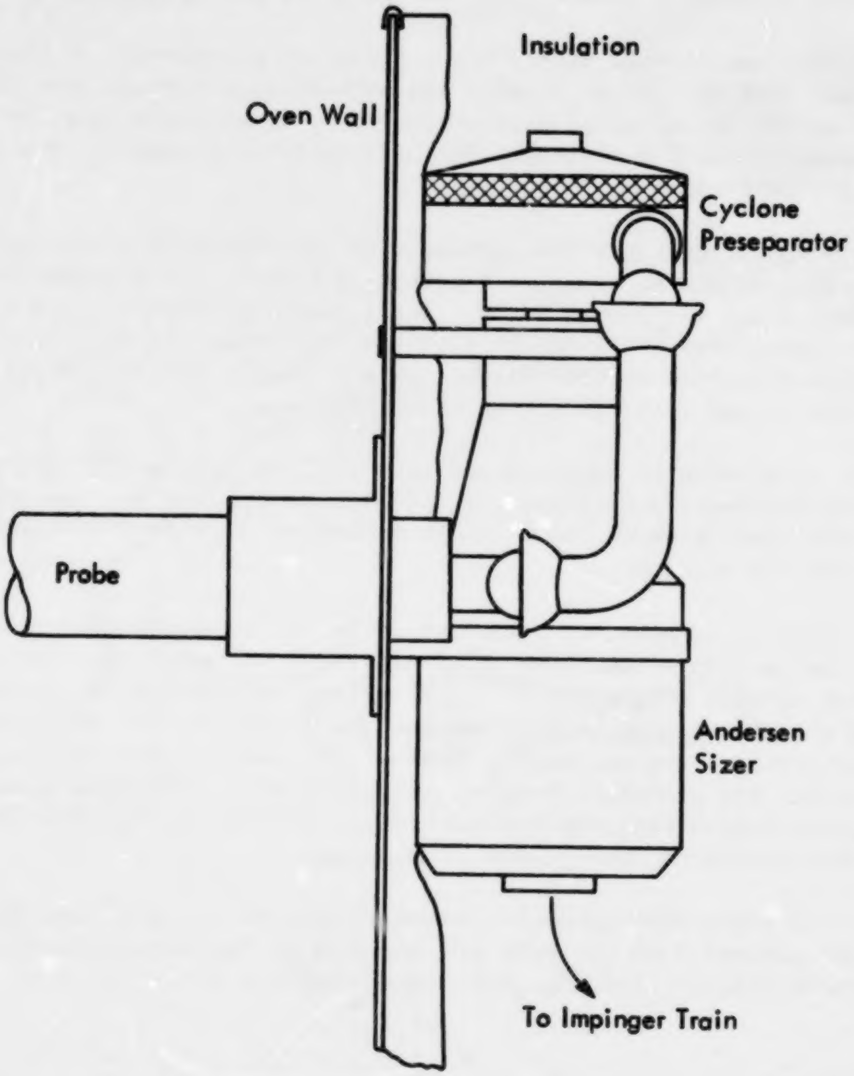

Insulation
Oven Wall
Cyclone
Preseparator
Probe
Andersen
Sizer
To Impinger Train

Figure 11. Placement of Andersen Sampling Head in an EPA Method 5 sampling train.

The probable presence of particles larger than 15 μ suggested the necessity of a cyclone preseparator. An Andersen preseparator was used. The manufacturer supplied a calibration curve for the preseparator used.

Each test was started with a clean probe and glassware. At the conclusion of each test the probe, nozzle, and connecting glassware were washed out with acetone and the rinsings were collected in a weighed beaker for weighing after evaporation of the acetone. During back-to-back testing, the washing was done in the field.

Each stage of the Mark III sampler with the exception of the back-up filter stage consists of a plate, a gasket, a filter, and a filter hold-down cross. Each stage was assembled on a small piece of aluminum foil which was marked for later use. This entire assembly, including the foil, was weighed on a precision balance to the nearest tenth milligram and the weight recorded. The foil was stored in a plastic bag for later use.

After completion of sampling and return to the laboratory, the probe, cylone, and glassware were rinsed of any particulate that may have been collected. The rinsings were placed under a chemical fume hood to evaporate the acetone used for rinsing.

The Andersen sampler was disassembled in the laboratory and each stage assembly then placed on the foil originally used for weighing. Each assembly was weighed and the weight was recorded. After evaporation of the acetone, the probe and cyclone washing beakers were weighed. Net weights were computed for the probe, cyclone, and collection stages. All particulates collected in the nozzle, probe, and glassware before the cyclone were considered probe collection. Everything collected from the entrance of the cyclone to the first stage of the sampler was considered the cyclone collection.

When two tests were conducted consecutively on the same day, the Andersen sampler was removed from the oven and returned to the laboratory for weighing of the loaded stages, cleaning, and preparation for the second test.

Orsat--

Orsat analyzers were used for the determination of oxygen, carbon dioxide, and carbon monoxide in the stack gas. A photograph of an Orsat analyzer is included in Figure 7e. The sample was obtained by hand pumping an appropriate volume of stack gas into the analyzer. The sample was then successively bubbled through chemicals in each of the Orsat pipettes to absorb CO_2, O_2, and CO in the stack gas. Nitrogen was determined by difference from the values of CO_2, O_2, and CO. These measurements determine the effective molecular weight of the stack gas as well as allow an estimate of the excess air in the effluent stream to be determined.

Oxides of Nitrogen (NO_x)--

The determination of nitrogen oxide (NO_x) emission was basically measured by EPA Method 7. This method consists of collecting a sample of stack gas in an evacuated flask containing a dilute sulfuric acid-hydrogen peroxide absorbing solution. A photograph of a NO_x sampling train is included in Figure 7f. The nitrogen oxides except for nitrous oxide (N_2O), are measured colorimetrically using a phenoldisulfonic acid (PDS) procedure.[1/]

Preliminary values of NO_x emission using the EPA recommended absorbing solution were found to be suspect. These values always appeared low relative to samples obtained simultaneously using higher percentages of absorbing solution. The difficulty appeared to be caused by the sulfur content of the stack gas and its reaction with the absorbing solution. Experiments were performed to determine if the percentage of hydrogen peroxide solution was statistically significant. At the 95% confidence level it was ascertained that a significant difference did exist. Further sampling and analysis yielded no significant differences at a 95% confidence level for absorbing solution from 1 to 9% hydrogen peroxide. Consequently, the ASTM[7/] 3% hydrogen peroxide absorbing solution was selected as the appropriate value for the NO_x measurements of the experimental runs of this study.

Oxides of Sulfur (SO_x)--

The determination of sulfur oxides (SO_x) emissions was determined by EPA Method 6 and reported as sulfur dioxide. This method consists of collecting the sample of stack gas by an EPA Method 5 sampling train modified with a glass wool particulate filter in the probe tip and a bypass section replacing the filter in the sample train oven. The sample train flow rate was adjusted to approximately 8 liters/min (0.3 cfm) and operated in the proportional sample mode at a single point in the exhaust stack cross section. The sample was collected over a period of approximately 30 min although it was eventually determined that the amount collected during this time span was more than sufficient for a reliable sample to be obtained. The sulfur dioxide, once collected, was measured by a barium-thorin titration method.[1/]

Aldehydes and Ketones--

The determination of aldehyde and ketone emissions was accomplished by the method of Carotti and Kaiser.[4/] This method consists of collecting the sample of stack gas by an EPA Method 5 sampling train modified with a glass wool particulate filter in the probe tip and a bypass section replacing the filter in the sample train oven. The sample train flow rate was adjusted to approximately 3 liters/min (0.1 cfm) and operated in the proportional sampling mode at a single point in the exhaust stack cross section. The sample was usually collected during a minimum sampling period of 30 min, although some collection times were as long as 70 min. The sample was absorbed in 1% aqueous sodium bisulfite ($NaHSO_3$) contained in the sample train impingers and quantitative determination was made as formaldehyde.

Organic Acids, Cyanide, and Phosphate--

The determination of organic acids, cyanide (CN), and phosphate (PO_4-3) emissions was accomplished by the method of Carotti and Kaiser.[4] This method consists of collecting the sample of stack gas by an EPA Method 5 sampling train modified with a glass wool particulate filter in the probe tip and a bypass section replacing the filter in the sample train oven. The sample train flow rate was adjusted to approximately 20 liters/min (0.7 cfm) and operated in the proportional sampling mode at a single point in the exhaust stack cross section. The sample was usually collected during a minimum sampling period of 30 min although some collection times were as long as 75 min. The sample was absorbed in a 1.5N solution of sodium hydroxide (NaOH) contained in the sample train impingers.

CN^- was determined by ion selective electrode after adding $ClCO_3$ to the impinger solutions to remove sulfide interference. Phosphorus was determined as PO_4^- by spectrophotometer after acidifying the impinger solution with H_2SO_4 and adding ammonium persulfate to release all organic phosphorus. Chloride was also determined from this train by a colorimetric method.

A number of methods were used to obtain results for organic acids. An ion chromatograph was found most satisfactory.

Chlorides--

The chloride emissions have been determined from the samples collected in two of the previously described sample train. Part of the impinger solution from the EPA Method 6 sulfur dioxide sampling train was analyzed for hydrochloric acid (HCl). The chlorides from this sample train were determined by a colorimetric method.

The organic acid sampling train was also used to determine chlorides, as reported by Carotti and Kaiser,[4] from an impinger in the sampling train which contained a 1.5N NaOH solution. The chlorides from this sample train were determined spectrophotometrically.

Mercury, Arsenic, Intimony, and Beryllium--

Mercury vapor in the stack effluent was generally collected by the Shannon[5] modification of the EPA Method 5 sampling train. The first impinger contained 0.5N HNO_3 and the second impinger contained 0.5N KOH. The solutions after sampling were analyzed by inductively coupled plasma for the presence of mercury, arsenic, antimony, and beryllium. A second mercury train with K_2CO_3 and ICl solutions was also used.[3] These solutions were also analyzed, after sampling, with the inductively coupled plasma unit for the above particular elements. In addition, a number of other elements were also quantified from these trains.

Hydrocarbons--

Total hydrocarbons in the C_1 to C_5 range were determined by a gas chromatograph. The method consists of collecting a sample of stack gas in a dry evacuated flask. The sample is then passed through a packing material in the column of the gas chromatograph. The packing material such as carboseive B successively retains the C_1 through C_5 species such that the chromatograph output signal indicates their presence.

Organics--

Stack gases were drawn through a heated probe and across a column of macroreticular resin (Tenex-GC) where the organics are collected. The organics including polychlorinated biphenols (PCB) and polynuclear aromatics (PNA, PAH, PCH, or POM) were determined quantitatively by a gas chromatograph, mass spectrometer system.

The sampling methods and classification schemes described in the literature[8] as well as those developed here and described above have been shown to be inadequate. However, some selected methods are clearly superior based on interpretation of bench tests and these better methods have been used to study stack gases and particulates. The progress to date with these samples is discussed here.

Gas phase samples--S sampling procedure was developed for the accumulation of vapor phase polynuclear aromatics (PA, PAH, PCH, or POM) on porous polymers and the subsequent removal from the polymer followed by preseparation with final separation and measurement by gas chromatography. Acenaphthylene, fluorene, anthracene, phenanthrene, and perylene present in 5-to 295-liter air samples at prepared concentrations of from 10^{-5} to 10^{-9} g/liter were tested. Recovery efficiencies of 90 to 100% were demonstrated. For other organic components recovery efficiencies of 40 to 100% were related to component volatility and air volume. These results on various designs of probes and various porous polymers (XAD-2, XAD-4, XE-340, and Tenax-GC) were used to design and fabricate a probe which was deemed suitable for both ambient air and hot stack gas sampling.

Particulate samples--A limited effort was expended in devising new schemes for the collection of particulate samples. However, the treatment of particulates was extensively tested for effectiveness in removal of absorbed organic matter. Four schemes--thermal desorption, column elution, Soxhlet extraction, and extraction by sonic vibration were tested. The latter two showed the most promise for isolating organic matter in a form most suitable for separation and measurement. Seven extraction solvents, diethylether, chloroform, hexane, cyclohexane, benzene, methylene chloride, and acetone were tested critically using sonic vibration and Soxhlet distillation. These tests included comparisons of collected particulates and comparisons of particulates which had been fortified with known amounts of PNA's. Test results have not been completely conclusive but some data show definitely that current extraction procedures may be inadequate. Positive results reported in the literature for some procedures are probably due to improper fortification procedures.

Water samples--The techniques for the measurement of PNA's, acenaphthylene, phenanthrene, fluoranthene, pyrene, anthracene, chrysene, perylene, and benzopyrene in water at the 20 to 500 g/liter level were established.

SECTION 7

RESULTS

GENERAL

Most of the results are reported in a data matrix format for each boiler unit. The independently controlled boiler parameters of percentage nominal RDF heat energy input (0, 20, or 50) and percentage nominal load (60, 80, or 100) are the major headings in the data matrix. The measured variable for each experimental run is tabulated in each cell of the data matrix along with its test number designation (EPA No.). Also for each cell, the cell average, cell standard deviation, and coefficient of variation (standard deviation divided by the mean) are tabulated.

Following each data matrix are plots of the measured variables as functions of both RDF heat energy input and boiler steam load. Each data point on the plot is the cell average, and the vertical bar through the data point represents the cell standard deviation. Thus, each data point usually represents the average of three experimental runs. It should be noted that two standard deviations on each side of the cell average would approximately correspond to the 95% statistical confidence band. This means that there would be about 95% probability that the actual value of the measured variable would be within a range of the two standard deviations on each side of the cell average.

Curves and lines drawn through the data points of these plots are meant to show general trends in the data. Such curves or lines are not meant to imply any particular mathematical expression which may (or may not) govern the behavior of a particular measured variable.

INPUT STREAMS

Coal

The heating value and ultimate analysis constituents for coal used in boiler unit Nos. 5 and 6 are tabulated respectively in Tables 9 and 10. The values of the average, the maximum, the minimum, the standard deviation, the coefficient of variation, and the sample size used for these determinations are given in these tables. The 95% confidence interval is also given based on the t statistic distribution.

Chemical analysis for the elements contained in the coal samples are presented by element alphabetically in the data matrix format in Appendix A. The same analysis listed by EPA run number for the tests performed on boiler unit Nos. 5 and 6 are contained in Appendix B. Based on measured coal flow rates the predicted flow rate of each element into the boiler is also tabulated in Appendix B.

Refuse Derived Fuel

The heating value and ultimate analysis constituents for RDF used in boiler unit Nos. 5 and 6 are tabulated respectively in Tables 9 and 10. The values of the average, the maximum, the minimum, the standard deviation, the coefficient of variation, and the sample size used for these determination are given in these tables. The 95% confidence interval is also given based on the t statistic distribution.

Chemical analysis for the elements contained in the RDF are presented by element alphabetically in the data matrix format in Appendix A. The same analysis listed by EPA run number for the tests performed on boiler unit No. 5 and 6 are contained in Appendix C. Based on measured RDF flow rates the predicted flow rate of each element into the boiler is also tabulated in Appendix C.

Air

Dry bulb temperature, wet bulb temperature, barometric pressure, and humidity are tabulated in Table 11. The average values of these measurements as well as the standard deviation is given for each test cell of given load and given amount of RDF input in this table.

TABLE 9. SUMMARY OF COAL, RDF, AND ASH CHARACTERISTICS FOR BOILER UNIT NO. 5

		Quantity	Mean	Maximum	Minimum	Standard deviation	Coefficient of variation	Sample size	95% Confidence interval ±	t Statistic
Coal: Iowa		HHV (kJ/kg)	21,848	23,057	20,804	--	0.0516	28	482	2.052
		FM	0.1081	0.1359	0.0772	0.0150	0.1389	28	0.0308	
		ASH	0.2024	0.2296	0.1818	0.0118	0.0581	28	0.0241	
		C	0.5171	0.5461	0.4872	0.0139	0.0269	28	0.0285	
	$\frac{kg}{kg}$	H	0.0396	0.0476	0.0316	0.0046	0.1162	28	0.0094	
		S	0.0666	0.0876	0.0532	0.0072	0.1080	28	0.0148	
		Cl	0.0004	0.0013	0	0.0003	0.9348	28	0.0007	
		O	0.0658	0.0948	0.0424	0.0116	0.1763	28	0.0238	
RDF		$\rho (kg/m^3)$	125.36	140.24	111.33	8.123	0.0648	18	1.0788	
		HHV (kJ/kg)	13,063	15,929	11,128	1,092	0.0836	18	991	2.110
		FM	0.2177	0.3012	0.1461	0.0324	0.1486	18	0.0683	
		ASH	0.1660	0.2419	0.1133	0.0320	0.1928	18	0.0675	
		C	0.3067	0.3726	0.2786	0.0239	0.0780	18	0.0505	
	$\frac{kg}{kg}$	H	0.0231	0.370	0.0166	0.0056	0.2424	18	0.0118	
		S	0.0040	0.0090	0.0019	0.0020	0.5035	18	0.0042	
		Cl	0.0025	0.0052	0.0018	0.0008	0.3346	18	0.0017	
		O	0.2703	0.3540	0.2110	0.0450	0.1665	18	0.0950	
% Load/% RDF		C %	8.59	12.25	5.97	2.79	0.325	4	8.078	
	60	H %	0.87	1.42	0.54	0.38	0.473	4	1.209	3.182
	0	S %	3.49	4.19	3.13	0.49	0.140	4	1.559	
		Mineral %	87.06	89.41	83.85	2.69	0.031	4	8.560	
Bottom Ash		C	7.50	10.9	5.78	2.37	0.315	4	7.541	
	60	H	0.86	1.02	0.70	0.13	0.151	4	0.414	3.182
	20	S	3.18	3.51	2.72	0.34	0.107	4	1.082	
		Mineral	88.46	90.48	84.71	2.61	0.030	4	8.305	
		C	7.01	8.[illegible]	5.66	1.25	0.178	3	5.379	
	60	H	0.90	0.[illegible]4	0.84	0.06	0.067	3	0.258	4.303
	50	S	2.31	3.25	1.63	0.84	0.364	3	3.615	
		Mineral	89.77	91.78	87.78	2.0	0.022	3	8.606	
% Load/% RDF		C %	8.81	9.69	8.35	0.77	0.087	3	3.313	
	80	H %	0.67	0.76	0.54	0.12	0.179	3	0.516	4.303
	0	S %	2.92	3.82	2.16	0.84	0.288	3	3.615	
		Mineral %	87.60	88.07	87.12	0.48	0.005	3	2.065	
		C	13.01	14.21	12.59	1.05	0.081	3	4.518	
	80	H	0.92	1.01	0.79	0.11	0.120	3	0.473	4.303
	20	S	3.54	4.13	2.75	0.71	0.201	3	3.055	
		Mineral	82.54	84.07	81.05	1.51	0.018	3	6.498	
Bottom Ash		C	6.84	2.88	1.71	1.22	0.178	3	5.250	
	80	H	0.77	0.97	0.66	0.17	0.221	3	0.732	4.303
	50	S	2.24	8.03	5.60	0.59	0.263	3	2.539	
		Mineral	90.15	92.03	88.12	1.96	0.022	3	8.434	
		C	9.44	12.46	7.81	2.62	0.278	3	11.274	
	100	H	0.77	0.94	0.51	0.23	0.299	3	0.990	4.303
	0	S	2.87	2.98	2.80	0.09	0.031	3	0.387	
		Mineral	86.91	88.53	84.05	2.49	0 029	3	10.714	
		C	9.64	11.30	8.68	1.44	0.149	3	6.196	
	100	H	0.63	0.74	0.45	0.16	0.254	3	0.688	4.303
	20	S	3.75	4.09	3.13	0.54	0.144	3	2.324	
		Mineral	85.96	87.22	84.16	1.[illegible]	0.019	3	6.885	
		C	11.16	13.32	8.99	3.06	0.274	2	38.880	
	100	H	0.70	1.01	0.38	0.45	0.643	2	5.718	12.706
	50	S	3.12	3.24	2.99	0.18	0.058	2	2.287	
		Mineral	85.04	87.39	82.68	3.33	0.039	2	42.311	

(continued)

TABLE 9. (Concluded)

		Quantity	Mean	Maximum	Minimum	Standard deviation	Coefficient of variation	Sample size	95% Confidence interval ±	t Statistic
% Load/%RDF		C %	12.83	20.15	8.39	5.08	0.396	4	16.165	3.182
	60	H %	0.65	0.82	0.55	0.12	0.185	4	0.382	
	0	S %	1.82	2.16	1.64	0.25	0.137	4	0.796	
		Mineral %	84.71	88.90	77.18	5.16	0.061	4	16.419	
		C	7.70	5.80	8.71	1.64	0.213	3	7.057	4.303
	60	H	0.60	0.79	0.43	0.18	0.300	3	0.775	
	20	S	2.14	2.33	1.85	0.26	0.121	3	1.119	
		Mineral	89.57	91.53	88.52	1.70	0.019	3	7.315	
Collector Ash		C	3.37	4.57	2.16	1.21	0.359	3	5.207	4.303
	60	H	0.51	0.67	0.34	0.17	0.333	3	7.32	
	50	S	1.03	1.14	0.91	0.12	0.117	3	0.516	
		Mineral	95.10	96.26	93.95	1.16	0.012	3	4.991	
		C	12.98	11.05	15.21	2.10	0.162	3	9.036	4.303
	80	H	0.61	0.65	0.55	0.05	0.082	3	0.215	
	0	S	1.98	2.07	1.93	0.08	0.040	3	0.344	
		Mineral	84.44	86.47	82.09	2.21	0.026	3	9.510	
		C	7.61	12.5	5.17	4.23	0.556	3	18.202	4.303
	80	H	0.43	0.44	0.41	0.02	0.047	3	0.086	
	20	S	3.66	4.22	2.55	0.96	0.262	3	4.131	
		Mineral	88.29	90.17	84.54	3.25	0.037	3	13.985	
		C	8.14	13.7	3.73	5.08	0.624	3	21.859	4.303
	80	H	0.67	0.85	0.38	0.26	0.388	3	1.119	
	50	S	2.33	2.61	1.97	0.33	0.142	3	1.420	
		Mineral	88.85	93.48	82.90	5.41	0.061	3	23.279	
% Load/% RDF		C %	17.97	26.71	12.16	7.71	0.429	3	33.176	4.303
	100	H %	0.53	0.68	0.32	0.19	0.358	3	0.818	
	0	S %	2.04	2.14	1.90	0.12	0.059	3	0.516	
		Mineral %	79.47	85.38	70.71	7.74	0.097	3	33.305	
Collector Ash		C	8.74	11.30	5.29	3.10	0.355	3	13.339	4.303
	100	H	0.56	00.59	0.51	0.04	0.071	3	0.172	
	20	S	2.61	2.85	2.33	0.26	0.100	3	1.119	
		Mineral	88.10	91.56	85.78	3.05	0.035	3	13.124	
		C	8.60	9.57	7.63	1.37	0.159	2	17.407	12.706
	100	H	0.81	0.90	0.72	0.13	0.160	2	1.652	
	50	S	2.53	2.81	2.24	0.40	0.158	2	5.082	
		Mineral	88.06	89.23	86.90	1.65	0.019	2	20.965	
OVERALL										
Bottom Ash		C	8.963	14.21	5.6	2.524	0.212	28	5.179	2.052
		H	0.795	1.42	0.38	0.214	0.269	28	0.439	
		S	3.07	4.19	1.63	0.7	0.227	28	1.436	
		Mineral	87.18	92.03	81.05	2.88	0.033	28	5.910	
Collector Ash		C	9.723	26.71	2.16	5.388	0.554	27	11.078	2.056
		H	0.590	0.90	0.32	0.156	0.265	27	0.545	
		S	2.210	4.22	1.03	0.756	0.342	27	0.703	
		Mineral	87.274	96.26	70.71	5.427	0.062	27	0.127	

TABLE 10. SUMMARY OF COAL, RDF, AND ASH CHARACTERISTICS FOR BOILER UNIT NO. 6

		Quantity	Mean	Maximum	Minimum	Standard deviation	Coefficient of variation	Sample size	95% Confidence interval ‡	t Statistic
Coal:		HHV(kJ/kg)	22,262	22,860	21,439	176	0.0184	9	407	2.306
Iowa/Wyoming		FM	0.1563	0.1666	0.1344	0.0108	0.0690	9	0.0249	
		Ash	0.1162	0.1336	0.1006	0.0119	0.1024	9	0.0274	
		C	0.5408	0.5572	0.5269	0.0092	0.0177	9	0.0213	
	kg	H	0.0416	0.0529	0.0371	0.0048	0.1154	9	0.0111	
	kg	S	0.0346	0.0676	0.0261	0.0064	0.1848	9	0.0148	
		Cl	0.0005	0.0007	0.0003	0.0001	0.2669	9	0.0003	
		O	0.1100	0.1260	0.0951	0.0097	0.0882	9	0.0224	
RDF		$\rho(kg/m^3)$	126.87	136.96	111.49	78.87	0.0785	6	1.5985	2.571
		HHV(kJ/kg)	12.532	13.179	11.514	1,872	0.1494	6	684	
		FM	0.2523	0.3112	0.2016	0.0393	0.1559	6	0.1011	
		Ash	0.1496	0.1696	0.1309	0.0150	0.1006	6	0.0387	
	kg	C	0.2957	0.3244	0.2737	0.0175	0.0592	6	0.0450	
	kg	H	0.0150	0.0217	0.064	0.0052	0.3467	6	0.1645	
		S	0.0031	0.0039	0.0023	0.0007	0.2231	6	0.0017	
		Cl	0.0031	0.0067	0.0020	0.0018	0.5890	6	0.0046	
		O	0.2813	0.3160	0.2600	0.0196	0.0683	6	0.0504	
% Load/% RDF		C %	3.77	7.50	1.32	3.28	0.870	3	14.114	4.303
	80	H %	0.81	0.94	0.66	0.14	0.173	3	0.602	
	0	S %	1.95	2.18	1.65	0.27	0.138	3	1.162	
		Mineral %	93.48	96.20	89.66	3.40	0.036	3	14.630	
Bottom Ash		C	2.84	3.34	2.56	0.43	0.151	3	1.850	4.303
	80	H	0.71	0.93	0.53	0.20	0.282	3	0.861	
	20	S	1.65	1.87	1.45	0.21	0.127	3	0.904	
		Mineral	94.79	95.46	94.09	0.69	0.007	3	2.969	
		C	2.31	2.54	2.12	0.21	0.091	3	0.904	4.303
	80	H	0.51	0.60	0.33	0.15	0.294	3	0.645	
	50	S	1.09	1.30	0.85	0.23	0.211	3	0.990	
		Mineral	96.09	96.43	95.83	0.31	0.003	3	1.334	
% Load/% RDF		C %	12.93	15.18	10.38	2.41	0.186	3	10.370	4.303
	80	H %	0.64	0.88	0.42	0.23	0.359	3	0.990	
	0	S %	1.68	1.80	1.58	0.11	0.065	3	0.473	
		Mineral %	84.75	87.55	82.36	2.62	0.031	3	11.274	
Collector Ash		C	9.51	10.11	9.20	0.52	0.055	3	2.238	4.303
	80	H	0.58	0.73	0.48	0.13	0.224	3	0.559	
	20	S	1.94	2.22	1.62	0.30	0.155	3	1.291	
		Mineral	87.97	88.09	87.73	0.21	0.002	3	0.245	
		C	10.17	15.36	6.98	4.54	0.446	3	19.536	4.303
	80	H	0.85	1.16	0.69	0.27	0.318	3	1.162	
	50	S	1.79	2.35	1.40	0.50	0.279	3	2.152	
		Mineral	87.19	90.46	81.60	4.87	0.056	3	20.956	
OVERALL										
Bottom Ash		C	2.974	7.50	1.32	1.778	0.598	9	4.100	2.306
		H	0.677	0.94	0.33	0.198	0.292	9	0.457	
		S	1.563	2.18	0.85	0.429	0.275	9	0.989	
		Mineral	94.786	96.43	89.66	2.078	0 022	9	4.792	
Collector Ash		C	10.869	15.36	6.98	3.025	0.278	9	6.976	2.306
		H	0.690	1.16	0.42	0.224	0.325	9	0.519	
		S	1.804	2.35	1.40	0.318	0.176	9	0.733	
		Mineral	86.637	90.46	81.60	3.124	0.036	9	7.204	

TABL[illegible].1. SUMMARY OF AIR, FEEDWATER, AND STEAM CHARACTERISTICS FOR BOILER UNIT NOS. 5 AND 6

Load (%)	RDF % nominal	EPA	Steam load (%)	RDF heat (%)	Air temperature Wet bulb °C	Air temperature Dry bulb °C	Relative humidity (%)	Barometric pressure kPa	Feedwater Flow kg/hr	Feedwater Temp. °C	Steam temp. °C	Pressure[a] kPa	Flow kg/hr
Unit No. 5													
60	0	4A	60.00	0	20	32	32	97.02	25,220	152	449	4,254	28,236
		4B	60.00	0	20	32	32	97.02	25,220	152	449	4,254	28,236
		20	59.47	0	20	32	32	98.71	22,312	151	439	4,309	26,331
		21	59.47	0	18	24	54	98.78	23,088	153	440	4,323	22,861
		36	58.95	0	21	31	39	97.32	22,203	129	435	4,334	26,331
		Ave	59.59	0	20	30.2	45.8	97.77	23,610	147.4	442	4,297	26,399
		SD	0.44	0	1.10	3.49	17.2	0.90	1,509	10.31	6.31	41	2,195
60	20	8	60.00	21.7	18.1	31	25	97.93	23,224	152	444	4,309	26,807
		9A	60.00	24.1	13	18	56	98.14	23,496	150	437	4,275	27,079
		9B	60.00	24.2	16	24	38	98.07	22,226	149	438	4,268	25,719
		33	60.00	16.0	23	31	48	98.21	20,911	134	436	4,323	25,174
		Ave	60.00	21.50	17.5	26	41.8	98.09	22,464	146.3	439	4,294	26,195
		SD	0.0	3.86	4.21	6.27	13.4	0.12	1,171	8.26	3.6	26	899
60	50	1	61.05	53.9	21	30	41	98.00	23,995	147	442	4,289	26,399
		34	59.47	54.9	22	30	50	97.66	21,686	135	449	4,357	26,399
		35	60.53	67.7	23	28	62	97.32	21,546	135	449	4,433	26,195
		Ave	60.35	58.83	22.0	29.3	51	97.66	22,408	139	447	4,360	26,331
		SD	0.81	7.70	1.0	1.15	10.5	0.34	1,376	6.93	4.0	72	118
80	0	5	80.00	0	17.5	30.3	26	98.00	32,205	139	457	4,243	35,584
		16	80.53	0	21	27	60	97.93	30,663	138	453	4,302	34,768
		17	81.05	0	24	31	58	97.83	30,164	139	457	4,323	35,040
		Ave	80.53	0	20.8	29.4	48	97.92	31,011	145.3	456	4,293	35,131
		SD	0.53	0	3.25	2.14	19.1	0.085	1,064	11.85	2.31	35	415
80	20	6	78.95	22.2	17	25	42	97.63	30,980	159	446	4,220	34,836
		12	78.95	31.6	21	29	46	97.90	29,484	158	452	4,289	34,087
		13	81.05	27.7	23	33	42	97.70	31,116	158	450	4,213	35,108
		Ave	79.65	27.17	20.3	29.0	43.3	97.84	30,527	158.3	449	4,241	34,677
		SD	1.21	4.72	3.06	4.0	2.3	0.13	906	0.58	3.06	42	529
80	50	2	80.00	46.5	21	28	56	97.26	30,844	159	455	4,140	34,087
		10	79.47	49.2	16	24	40	98.00	29,438	156	460	4,164	34,292
		15	77.89	39.5	20	34.7	24	98.21	29,084	140	451	4,213	33,407
		Ave	79.12	45.07	19	28.9	39.3	97.82	29,789	141.7	455	4,172	33,929
		SD	1.10	5.01	2.65	5.41	15.0	0.50	931	10.21	4.51	37	463
100	0	11	97.37	0	20	29	43	98.00	37,920	161	442	4,351	43,069
		31	97.89	0	19	23	69	98.34	38,873	147	[illegible]	4,309	41,232
		32	93.16	0	23	28	69	98.27	37,195	145	444	4,323	40,075
		Ave	96.14	0	21	27	60.3	98.20	37,996	151	447	4,328	41,459
		SD	2.59	0	2.08	3.21	15.0	0.18	842	8.72	7.57	21	1.510
100	20	7	97.89	20.8	20	31	32	97.36	37,195	164	439	4,337	42,456
		14	94.74	26.6	18	31	25	98.27	34,745	138	454	4,289	39.599
		19	92.63	29.5	20	26	59	98.48	37,784	144	433	4,282	41,504
		Ave	95.09	25.63	19	29	38.7	98.04	36,575	148.7	442	4,303	41,186
		SD	2.65	4.43	1.15	2.89	18.0	0.60	1,612	13.6	10.8	30	1,455
100	50	3	92.63	40.9	19	23	66	96.95	38,011	167	481	4,302	56,404
		18	96.84	44.3	24	28	76	98.04	37,966	143	456	4,337	42,048
		Ave	94.74	42.6	21.5	25.5	71	97.50	37,989	155	468.5	4,320	49,226
		SD	2.98	2.40	3.54	3.54	7.1	0.77	31.8	17.0	17.7	25	10,151
Unit No. 6													
80	0	24	80.40	0	19	26	49	97.80	45,772	168	446	4,502	49,464
		29	79.20	0	16	19	66	98.51	45,391	168	448	4,557	47,423
		30	81.20	0	26	30	70	98.27	46,412	167	445	4,599	49,736
		Ave	80.27	0	20.3	25.0	61.7	98.19	45,858	167.7	446	4,553	48,874
		SD	1.01	0	5.13	5.57	11.2	0.36	516	0.58	1.53	49	1,264
80	20	25	80.80	19.5	23	29	63	97.66	46,126	166.7	449	4,557	50,281
		26	81.20	21.2	26	30	70	97.90	44,225	167	446	4,585	50,145
		27	79.20	21.5	24	30	63	97.93	45,382	167	448	4,551	49,056
		Ave	80.40	20.73	24	29.7	65.3	97.83	45,244	167	448	4,564	49,827
		SD	1.06	1.08	1.53	0.58	4.0	0.15	958	0.17	1.53	18	671
80	50	22	79.20	47.8	23	30	52	97.49	46,266	167	444	4,633	48.321
		23	79.20	54.6	18	23	64	98.24	46.706	169	445	4,551	48,920
		28	78.40	32.2	21	30	45	97.66	44,375	166	447	4,544	48,444
		Ave	78.93	44.87	20.7	27.7	53.7	97.80	45,782	167	445	4,576	48,562
		SD	0.46	11.48	2.52	4.04	9.6	0.39	1,238	1.53	1.53	49	316

[a] Absolute pressure.

EXIT STREAMS

Ash

Grate (Bottom) Ash--

The bottom (grate) ash characteristics including the combustible fraction of carbon, hydrogen, and sulfur are reported in Tables 9 and 10. The data reported include average values, maximum, minimum, standard deviation, coefficient of variation, and sample size. The 95% confidence interval is also given based on the t statistic distribution.

The results of the chemical analysis of the ash are given in Appendix A in the data matrix format. The sample analysis listed by EPA run number is given in Appendix D. Based on measured flow rates of grate ash, the predicted flow rate of each element out of the boiler is also tabulated in Appendix D.

Hopper (Fly) Ash--

The hopper ash characteristics are presented in Table 9 and Table 10. The combustible fractions of carbon, hydrogen, and sulfur are reported in these tables. The data presented includes average values, maximum, minimum, standard deviation, coefficient of variation, and sample size.

A chemical analysis for the elements in the hopper ash has also been performed and the results are given in the Appendix A in the data matrix format. The same analysis listed by EPA run number is given in Appendix E. Based on measured flow rates of hopper ash, predicted flow rate of each element out of the boiler is also tabulated in Appendix E.

Steam

The steam flow rate, steam temperature, steam pressure, feedwater flow rate, and feedwater temperature are tabulated in Table 11.

The averages of these quantities and their standard deviations are given for each test cell of given load and given amount of RDF input.

The feedwater flow rate was monitored as a check on the steam flow integrator reading. However, as can be seen from Table 11, the feedwater flow rate measurement was consistently below the steam integrator reading of each boiler. Checks on the calibrations of the steam flow measurement devices have revealed the steam flow integrator reading to be the appropriate flow rate. All steam loads of this study were consequently obtained from the steam flow integrator reading.

Stack Effluents

Particulates--

The results for the particulate matter, measured as a portion of the stack effluents, are summarized in the data matrix format of Tables 12 and 13 for boiler units Nos. 5 and 6, respectively. The results for the particulate effluent, measured before the particulate collector, are summarized in the data matrix format of Tables 14 and 15. The grams of particulate emitted per megajoule of heat energy input to the boiler are shown in Figures 12 and 13, respectively, as a function of actual RDF heat energy input to the boiler and actual steam load of the boiler. Figures 14 and 15 are similar plots except that the particulate matter has been sampled from ports located before the particulate collector. Figures 16 and 17 are plots showing the collector efficiency as determined from the particulate measurements obtained from locations both before (BPC) and after (stack) the particulate collectors.

Figures 16 and 17 show that the particulate emissions from the stack of boiler unit No. 5 decrease with RDF heat energy input at both the 80 and 100% steam load conditions. However, for the 60% load condition, the particulate emissions increase with increases in RDF heat energy input. For boiler unit No. 6, the particulate emissions also increase with increases in RDF heat energy input. Thus, for boiler unit Nos. 5 and 6, with 80% load condition, the trends in particulate emission rates appear to be opposite. However, it should be noted that some factors not controlled in the experiment may explain the apparent reversal in trends between the two traveling grate stoker units. The major factor in this category is excess air. Figures 18 and 19 are plots showing the variation in excess air with RDF heat energy input and steam load, respectively. These plots show that the amount of excess air at 80% steam load generally increases for boiler unit No. 6 and, except for the 80% load condition, appear to also increase for boiler unit No. 5 with RDF heat energy input. However, the trends of particulate effluent with RDF are not always the same as the trends of excess air with RDF.

Except for the 80% load tests on boiler unit No. 5, the excess air supplied to the boiler generally increases with corresponding increases in RDF heat energy input. However, the excess air generally decreases with increases in boiler load as shown in Figure 19.

The particulate effluent measured before the particulate collector appears to have less consistent trends and much more variation that corresponding particulate effluent measured in the stack. Results of the collector efficiency are presented in Tables 16 and 17.

TABLE 12. DATA MATRIX OF UNIT NO. 5 STACK PARTICULATE EMISSIONS

```
EMISSION RATE, GRAMS PER MEGAJOULE, STACK,CONC
BOILER NUMBER 5
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

*********************************************************************************
*           *                                                                   *
* PERCENT   *                          PERCENT LOAD                             *
*           *********************************************************************
* REFUSE    *                       *                      *                    *
*           *          60           *          80          *         100        *
*           *                       *                      *                    *
*********************************************************************************
*           *  EPA#  (GM/MEGJ)      *  EPA#  (GM/MEGJ)     *  EPA#  (GM/MEGJ)   *
*           *  04A     7.33E-01     *  05      4.05E-01    *  11      3.23E-01  *
*           *  04B     9.64E-01     *  17      1.06E 00    *  31      1.65E 00  *
*           *  20      4.93E-01     *                      *  32      2.02E 00  *
*           *  21      7.64E-01     *                      *                    *
*           *  36      1.69E 00     *                      *                    *
*     0     *                       *                      *                    *
*           *  AVE     9.08E-01     *  AVE     7.31E-01    *  AVE     1.33E 00  *
*           *   SD     4.81E-01     *   SD     4.61E-01    *   SD     8.94E-01  *
*           *   CV     5.30E-01     *   CV     6.31E-01    *   CV     6.71E-01  *
*********************************************************************************
*           *  EPA#  (GM/MEGJ)      *  EPA#  (GM/MEGJ)     *  EPA#  (GM/MEGJ)   *
*           *  08      4.97E-01     *  06      3.89E-01    *  07      4.00E-01  *
*           *  09A     1.54E 00     *  12      3.25E-01    *  14      2.96E-01  *
*           *  09B     6.10E-01     *  13      3.94E-01    *  19      3.55E-01  *
*           *  33      1.54E 00     *                      *                    *
*    20     *                       *                      *                    *
*           *  AVE     1.05E 00     *  AVE     3.69E-01    *  AVE     3.50E-01  *
*           *   SD     5.73E-01     *   SD     3.84E-02    *   SD     5.22E-02  *
*           *   CV     5.46E-01     *   CV     1.04E-01    *   CV     1.49E-01  *
*********************************************************************************
*           *  EPA#  (GM/MEGJ)      *  EPA#  (GM/MEGJ)     *  EPA#  (GM/MEGJ)   *
*           *  01      5.14E-01     *  02      2.70E-01    *  03S     2.75E-01  *
*           *  34      1.35E 00     *  10      3.43E-01    *  18      4.52E-01  *
*           *  35      1.89E 00     *  15      4.00E-01    *                    *
*           *                       *                      *                    *
*    50     *                       *                      *                    *
*           *  AVE     1.25E 00     *  AVE     3.38E-01    *  AVE     3.64E-01  *
*           *   SD     6.93E-01     *   SD     6.51E-02    *   SD     1.25E-01  *
*           *   CV     5.54E-01     *   CV     1.93E-01    *   CV     3.44E-01  *
*********************************************************************************
```

TABLE 13. DATA MATRIX OF UNIT NO. 6 STACK PARTICULATE EMISSIONS

EMISSION RATE, GRAMS PER MEGAJOULE, STACK,CONC
BOILER NUMBER 6
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

PERCENT REFUSE	PERCENT LOAD		
	60	80	100
0	EPA# (GM/MEGJ)	EPA# (GM/MEGJ) 24 6.02E-01 29 5.25E-01 30 3.39E-01 AVE 4.88E-01 SD 1.35E-01 CV 2.77E-01	EPA# (GM/MEGJ)
20	EPA# (GM/MEGJ)	EPA# (GM/MEGJ) 25 5.05E-01 26 6.46E-01 27 8.75E-01 AVE 6.76E-01 SD 1.87E-01 CV 2.76E-01	EPA# (GM/MEGJ)
50	EPA# (GM/MEGJ)	EPA# (GM/MEGJ) 22 1.02E 00 23 1.01E 00 28 7.59E-01 AVE 9.30E-01 SD 1.48E-01 CV 1.59E-01	EPA# (GM/MEGJ)

TABLE 14. DATA MATRIX OF UNIT NO. 5 PARTICULATE FLOW RATE BEFORE THE PARTICULATE COLLECTOR

```
EMISSION RATE, GRAMS PER MEGAJOULE,  BPC , CONC
BOILER NUMBER 5
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

*************************************************************************
*          *                                                            *
* PERCENT  *                      PERCENT LOAD                          *
*          **************************************************************
* REFUSE   *                    *                    *                  *
*          *        60          *        80          *       100        *
*          *                    *                    *                  *
*************************************************************************
*          * EPA# (GM/MEGJ)     * EPA# (GM/MEGJ)     * EPA# (GM/MEGJ)   *
*          * 04A    3.05E 00    * 05     3.81E 00    * 11     2.86E 00  *
*          * 04B    3.01E 00    * 16     2.87E 00    * 31     4.86E 00  *
*          * 20     3.18E 00    * 17     4.01E 00    * 32     4.64E 00  *
*          * 21     2.63E 00    *                    *                  *
*          * 36     3.91E 00    *                    *                  *
*    0     *                    *                    *                  *
*          * AVE    3.16E 00    * AVE    3.56E 00    * AVE    4.12E 00  *
*          *  SD    4.70E-01    *  SD    6.07E-01    *  SD    1.10E 00  *
*          *  CV    1.49E-01    *  CV    1.70E-01    *  CV    2.67E-01  *
*************************************************************************
*          * EPA# (GM/MEGJ)     * EPA# (GM/MEGJ)     * EPA# (GM/MEGJ)   *
*          * 08     3.96E 00    * 06     4.04E 00    * 07     3.18E 00  *
*          * 09A    5.13E 00    * 12     4.32E 00    * 14     1.94E 00  *
*          * 09B    4.86E 00    * 13     3.84E 00    * 19     1.56E 00  *
*          * 33     3.85E 00    *                    *                  *
*   20     *                    *                    *                  *
*          * AVE    4.45E 00    * AVE    4.07E 00    * AVE    2.23E 00  *
*          *  SD    5.44E-01    *  SD    2.41E-01    *  SD    8.45E-01  *
*          *  CV    1.45E-01    *  CV    5.92E-02    *  CV    3.80E-01  *
*************************************************************************
*          * EPA# (GM/MEGJ)     * EPA# (GM/MEGJ)     * EPA# (GM/MEGJ)   *
*          * 01     1.83E 00    * 10     3.56E 00    * 03S    4.01E 00  *
*          * 34     3.96E 00    * 15     3.30E 00    * 18     2.24E 00  *
*          * 35     4.58E 00    *                    *                  *
*          *                    *                    *                  *
*   50     *                    *                    *                  *
*          * AVE    3.46E 00    * AVE    3.43E 00    * AVE    3.13E 00  *
*          *  SD    1.44E 00    *  SD    1.87E-01    *  SD    1.25E 00  *
*          *  CV    4.16E-01    *  CV    5.46E-02    *  CV    4.00E-01  *
*************************************************************************
```

TABLE 15. DATA MATRIX OF UNIT NO. 6 PARTICULATE FLOW RATE BEFORE THE PARTICULATE COLLECTOR

```
EMISSION RATE, GRAMS PER MEGAJOULE,  BPC , CONC
BOILER NUMBER 6
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

***************************************************************************
*          *                                                              *
*          *                        PERCENT LOAD                          *
* PERCENT  *                                                              *
*          ****************************************************************
* REFUSE   *                    *                    *                    *
*          *        60          *        80          *       100          *
*          *                    *                    *                    *
***************************************************************************
*          *  EPA# (GM/MEGJ)    *  EPA# (GM/MEGJ)    *  EPA# (GM/MEGJ)    *
*          *                    *  24     2.69E 00   *                    *
*          *                    *  29     2.99E 00   *                    *
*          *                    *  30     1.74E 00   *                    *
*          *                    *                    *                    *
*    0     *                    *                    *                    *
*          *                    *  AVE    2.47E 00   *                    *
*          *                    *   SD    6.54E-01   *                    *
*          *                    *   CV    2.64E-01   *                    *
***************************************************************************
*          *  EPA# (GM/MEGJ)    *  EPA# (GM/MEGJ)    *  EPA# (GM/MEGJ)    *
*          *                    *  25     3.52E 00   *                    *
*          *                    *  26     3.70E 00   *                    *
*          *                    *  27     3.19E 00   *                    *
*          *                    *                    *                    *
*   20     *                    *                    *                    *
*          *                    *  AVE    3.47E 00   *                    *
*          *                    *   SD    2.57E-01   *                    *
*          *                    *   CV    7.41E-02   *                    *
***************************************************************************
*          *  EPA# (GM/MEGJ)    *  EPA# (GM/MEGJ)    *  EPA# (GM/MEGJ)    *
*          *                    *  22     5.24E 00   *                    *
*          *                    *  23     4.36E 00   *                    *
*          *                    *  28     3.53E 00   *                    *
*          *                    *                    *                    *
*   50     *                    *                    *                    *
*          *                    *  AVE    4.38E 00   *                    *
*          *                    *   SD    8.53E-01   *                    *
*          *                    *   CV    1.95E-01   *                    *
***************************************************************************
```

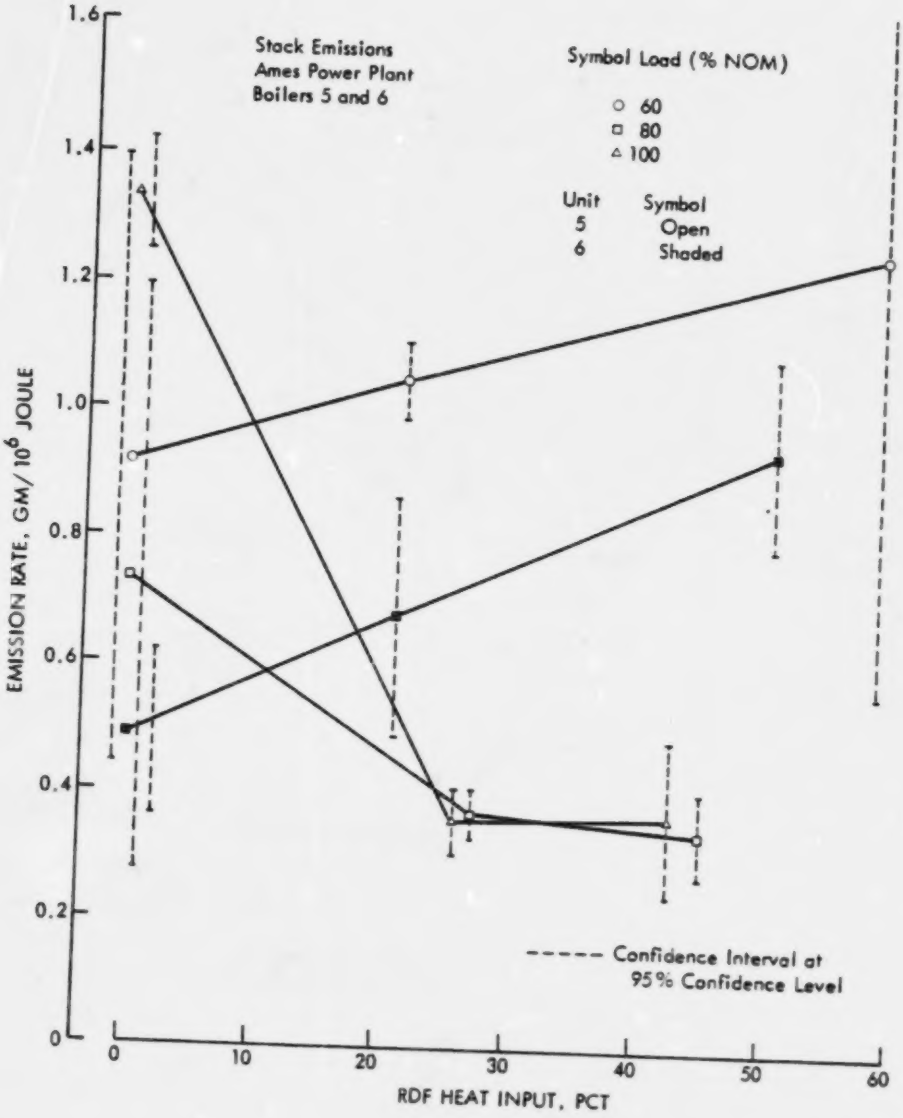


Figure 12. Stack particulate emission rate of boiler unit Nos. 5 and 6 as a function of refuse derived fuel heat input.

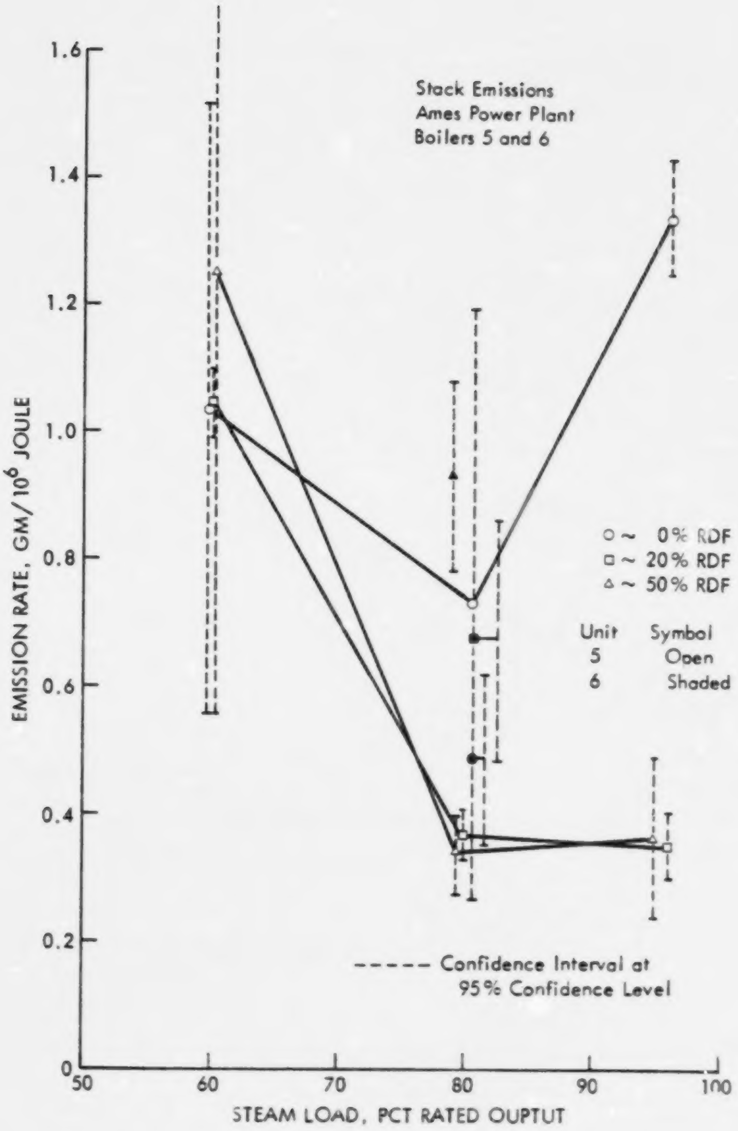


Figure 13. Stack particulate emission rate of boiler unit Nos. 5 and 6 as a function of steam load.

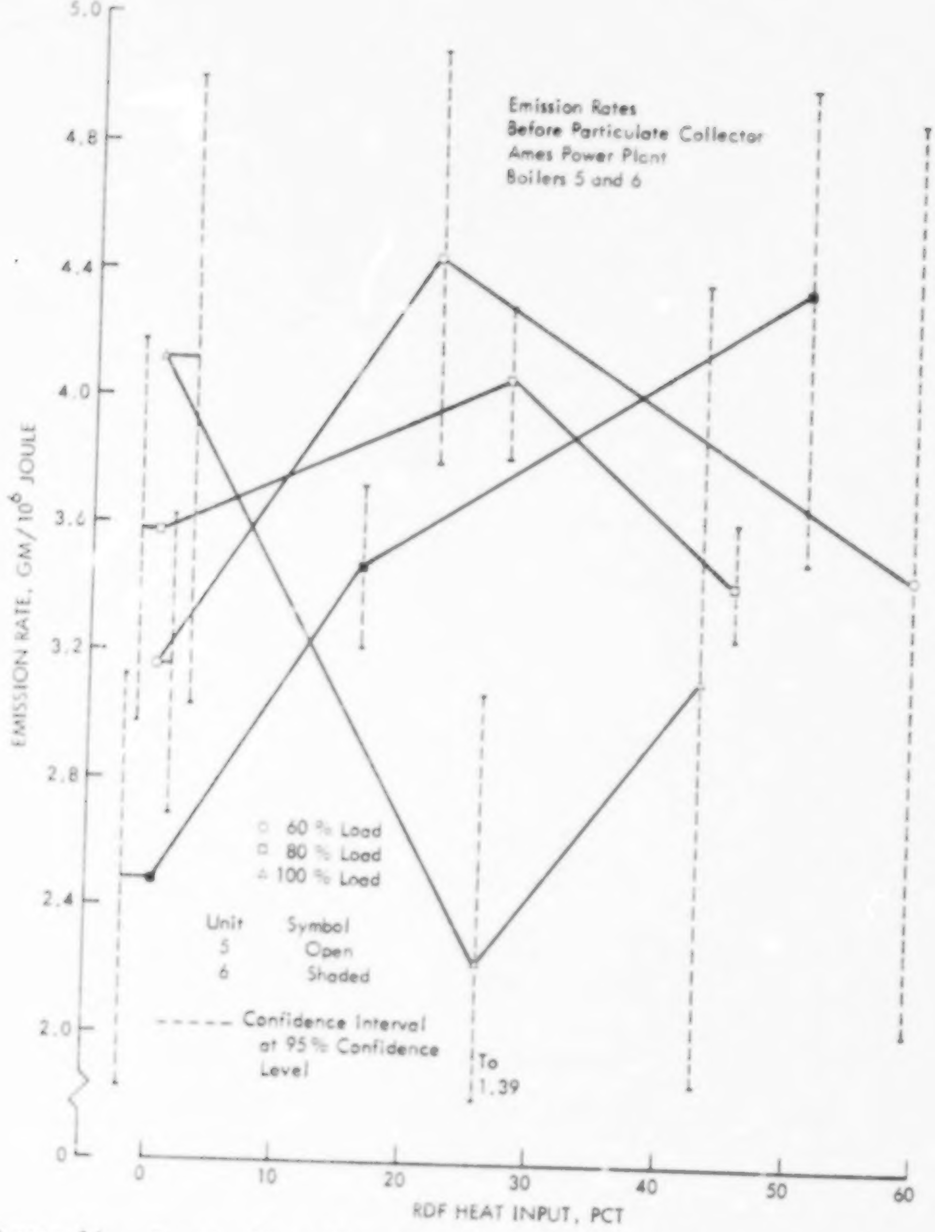


Figure 14. Particulate flow rate of boiler unit Nos. 5 and 6 before-the-particulate-collector as a function of refuse derived fuel heat input.

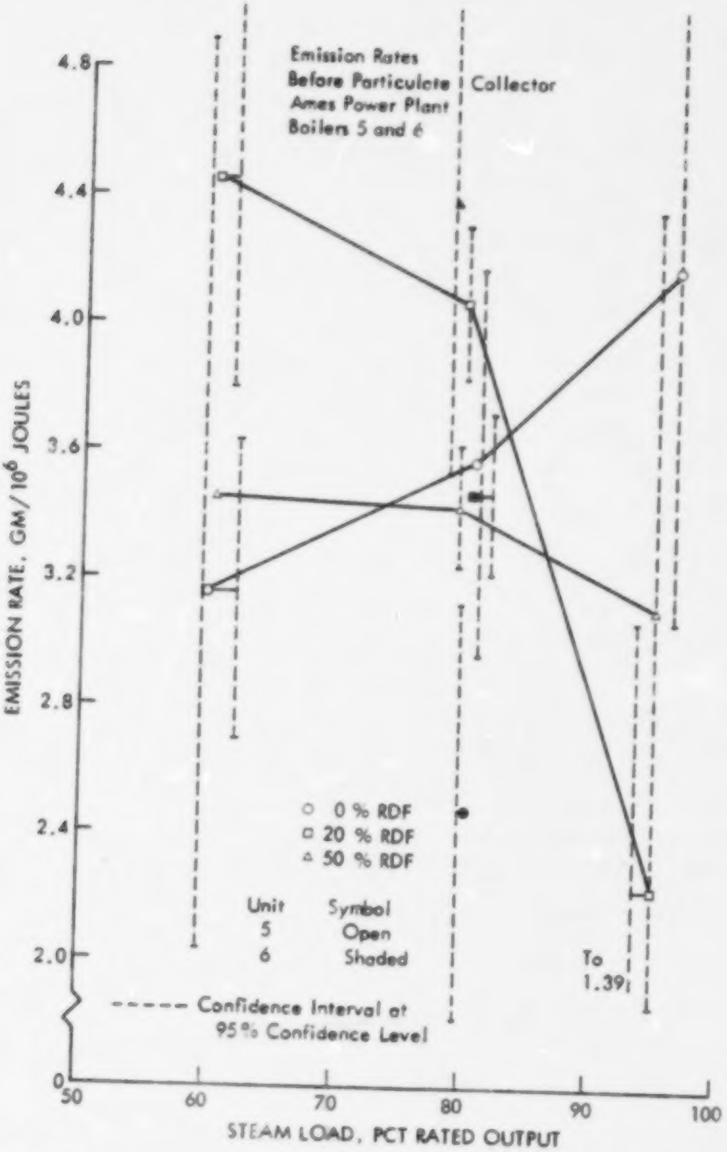


Figure 15. Particulate flow rate of boiler unit Nos. 5 and 6 before-the-particulate-collector as a function of steam load.

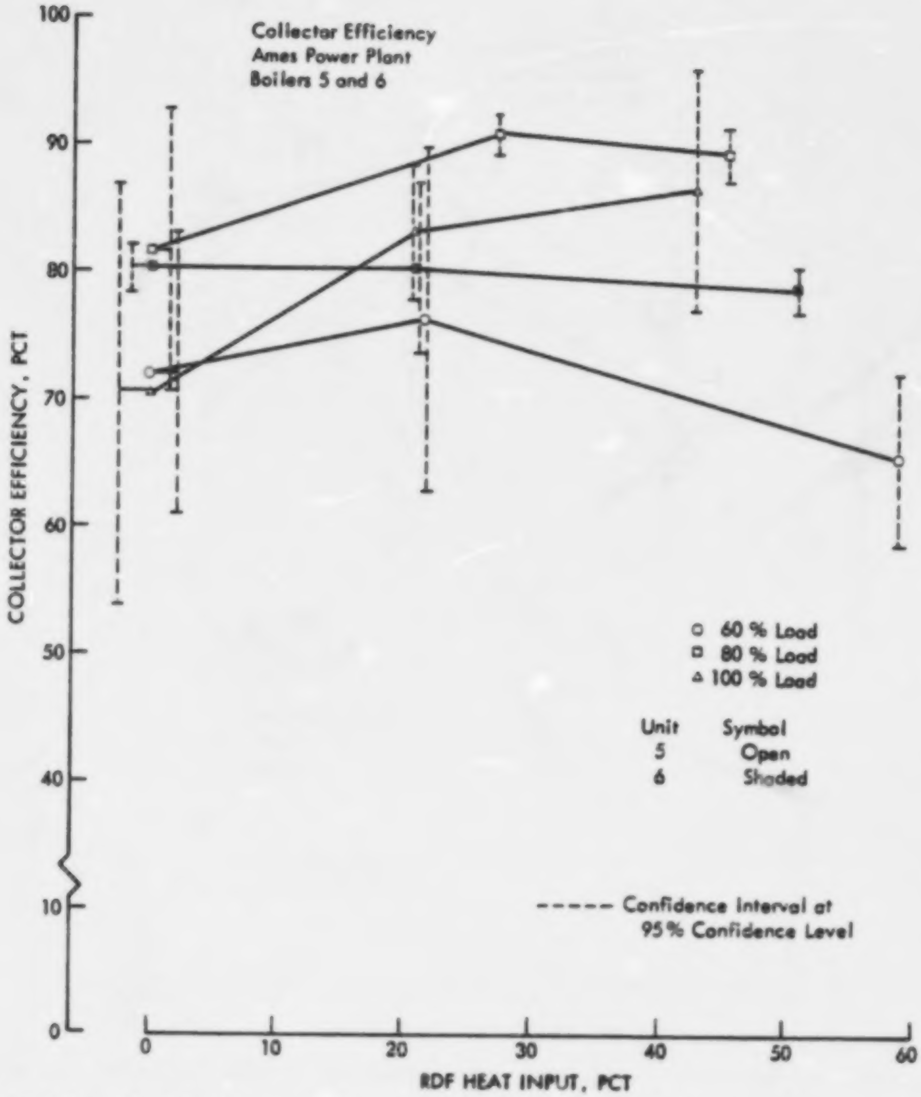


Figure 16. Particulate collector efficiency of boiler unit Nos. 5 and 6 as a function of refuse derived fuel heat input.

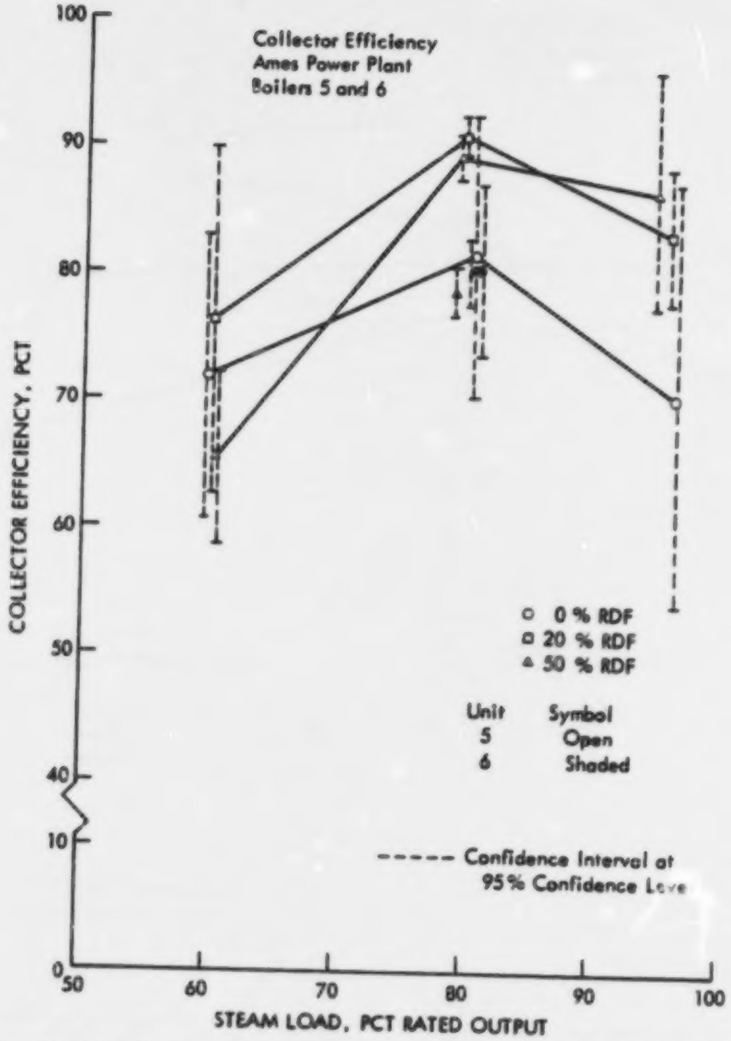


Figure 17. Particulate collector efficiency of boiler unit Nos. 5 and 6 as a function of steam load.

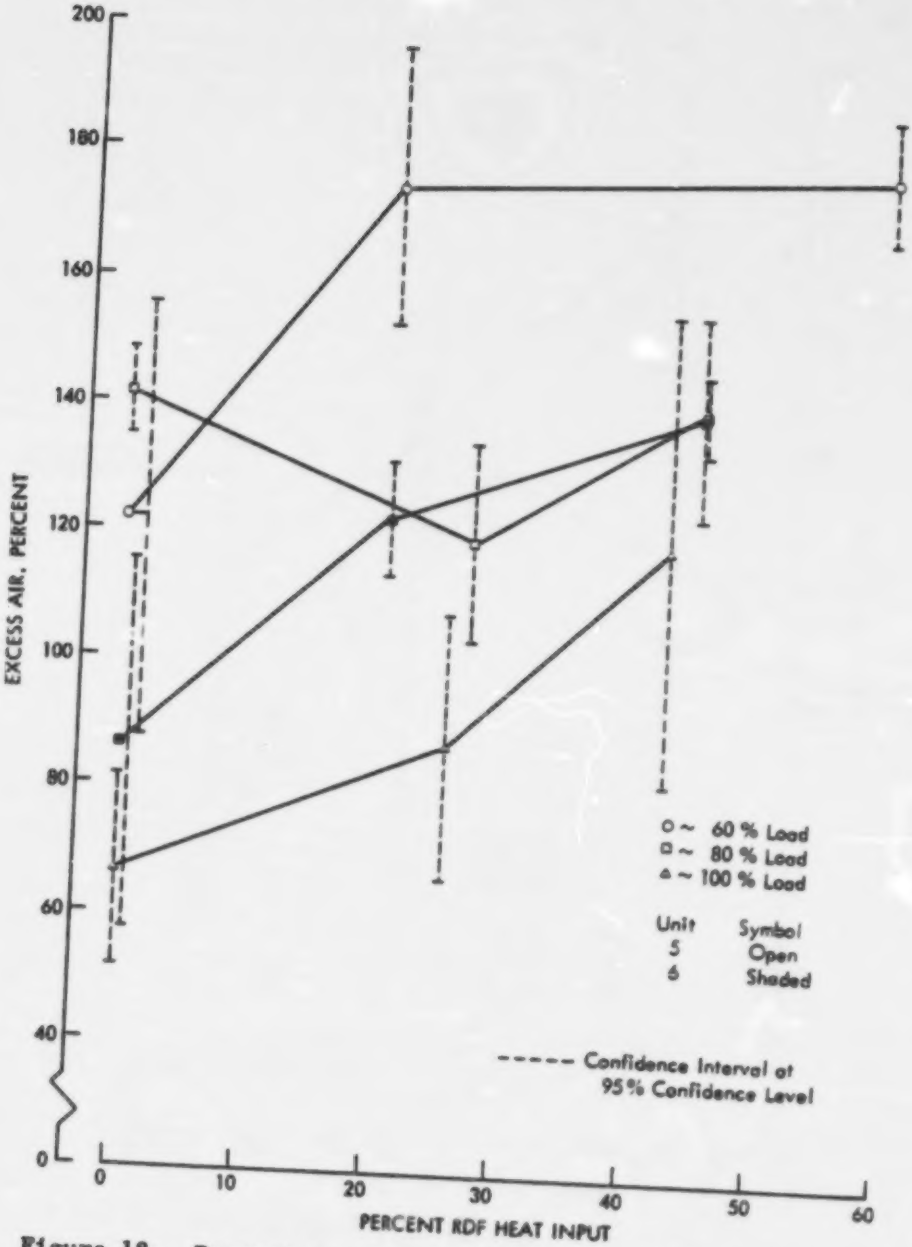


Figure 18. Percent excess air of boiler unit Nos. 5 and 6 as a function of refuse derived fuel heat input.

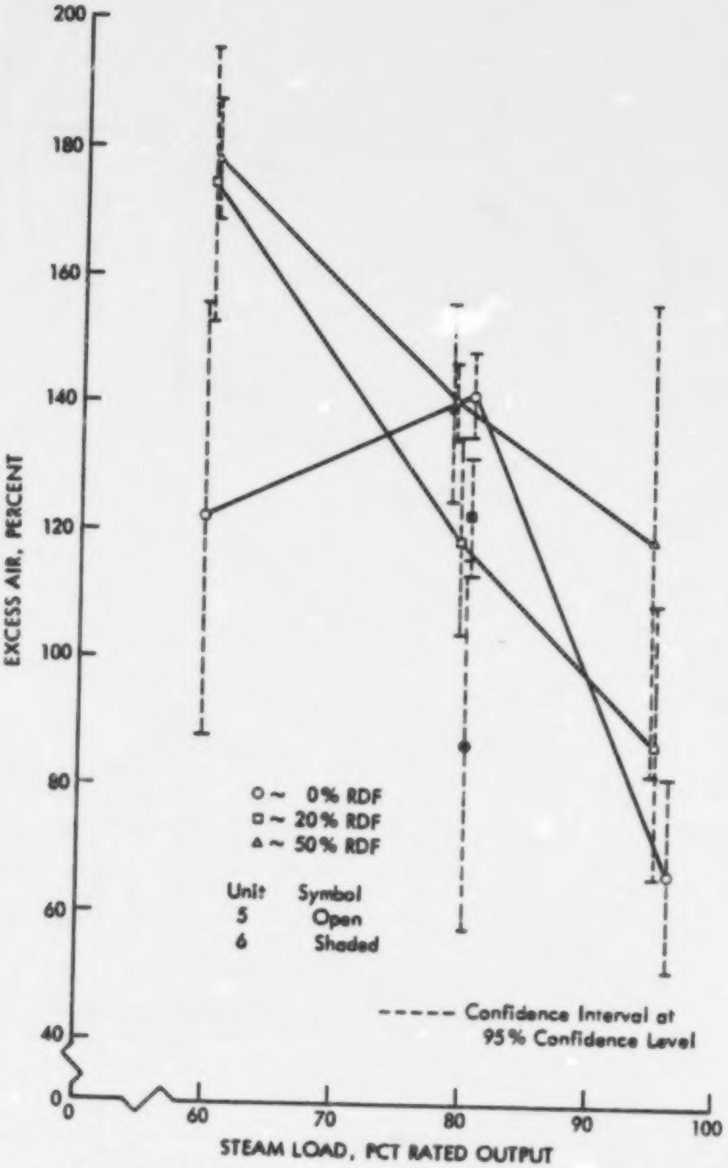


Figure 19. Percent excess air of boiler unit Nos. 5 and 6 as a function of steam load.

TABLE 16. DATA MATRIX OF BOILER UNIT NO. 5 PARTICULATE COLLECTOR EFFICIENCY

COLLECTOR EFFICIENCY
BOILER NUMBER 5
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

PERCENT REFUSE	PERCENT LOAD					
	60		80		100	
0	EPA#		EPA#		EPA#	
	04A	7.59E-01	05	8.94E-01	11	8.87E-01
	04B	6.80E-01	17	7.36E-01	31	6.61E-01
	20	8.76E-01			32	5.63E-01
	21	7.10E-01				
	35	5.69E-01				
	AVE	7.19E-01	AVE	8.15E-01	AVE	7.04E-01
	SD	1.12E-01	SD	1.12E-01	SD	1.66E-01
	CV	1.56E-01	CV	1.37E-01	CV	2.36E-01
20	EPA#		EPA#		EPA#	
	08	8.74E-01	06	9.04E-01	07	8.74E-01
	09A	7.00E-01	12	9.25E-01	14	8.47E-01
	09B	8.75E-01	13	8.97E-01	19	7.72E-01
	33	5.99E-01				
	AVE	7.62E-01	AVE	9.09E-01	AVE	8.31E-01
	SD	1.36E-01	SD	1.46E-02	SD	5.29E-02
	CV	1.79E-01	CV	1.61E-02	CV	6.36E-02
50	EPA#		EPA#		EPA#	
	01	7.20E-01	10	9.04E-01	03S	9.31E-01
	34	6.59E-01	15	8.79E-01	18	7.98E-01
	35	5.87E-01				
	AVE	6.55E-01	AVE	8.91E-01	AVE	8.64E-01
	SD	6.66E-02	SD	1.77E-02	SD	9.41E-02
	CV	1.02E-01	CV	1.98E-02	CV	1.09E-01

TABLE 17. DATA MATRIX OF BOILER UNIT NO. 6 PARTICULATE COLLECTOR EFFICIENCY

COLLECTOR EFFICIENCY
BOILER NUMBER 6
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

PERCENT REFUSE	PERCENT LOAD			
	[illegible]	80		100
0	EPA#	EPA#		EPA#
		24	7.76E-01	
		29	8.25E-01	
		30	8.05E-01	
		AVE	8.02E-01	
		SD	2.46E-02	
		CV	3.07E-02	
20	EPA#	EPA#		EPA#
		25	8.56E-01	
		26	8.25E-01	
		27	7.26E-01	
		AVE	8.02E-01	
		SD	6.79E-02	
		CV	8.46E-02	
50	EPA#	EPA#		EPA#
		22	8.04E-01	
		23	7.69E-01	
		28	7.85E-01	
		AVE	7.86E-01	
		SD	1.75E-02	
		CV	2.23E-02	

Regardless of the variation and trend reversals sometimes noted in the measured particulates before the collector and in the stack, the trends in collector efficiency are very consistent. Figures 16 and 17 indicate that the collector efficiency increases for a given load as the RDF heat energy input increases. For each given percentage of RDF, it is clear that an optimum collector efficiency is reached approximately in the vicinity of 80% steam load. However, cyclone collector efficiency, for a given cyclone design, is a function of such factors as particle concentration, gas flow rate, particle size, and particle density. Both boiler load and percent RDF may affect some or all of these factors. Future studies are planned to determine the particle size distribution of the particulates entering the collector which will aid in the understanding of collector efficiency.

Results of the analysis for the chemical element composition of the particulates collected on the quartz fiber filters of the EPA Method 5 sampling train are given in the data matrix format in Appendix F. The chemical element composition of the very small particulates passing through the filter, but captured in the sample train impinger water, are also tabulated in the data matrix format of Appendix F. In Appendix F the listing is alphabetical by element with boiler unit No. 5 data preceding boiler unit No. 6 data. Data for the before collector particulates, as well as the stack particulates, are included.

The chemical element composition of the particulates is presented by EPA test sequence in Appendix G for the stack particulates, and Appendix H for the BCP. Based on the measured flow rates of particulates and the chemical analysis of the particulates collected on the filter, predicted effluent rates of the chemical elements have been estimated and tabulated in these appendices. Such element effluent rates have been estimated based both on the filter catch and the total particulate catch of filter, cyclone, and sampling probe.

The chemical element composition of the particulates collected in the impinger water is presented by EPA test sequence in Appendix I for the stack particulates and Appendix J for the BCP. Based on the measured flow rates of particulates and the chemical analysis of the particulates collected in the impinger water, predicted effluent rates of the chemical elements have been estimated and tabulated in these appendices. Such element effluent rates have been estimated based on the amount of particulate trapped in the impinger water.

Particulate Sizing--

Particulate size distributions were determined from the net weight of particles collected on each stage of the Andersen sampler. The manufacturer's calibration was used to estimate the size collection for each stage. The amount of particulate passing through the probe tip but not reaching the cyclone was weighed as was the amount of particulate collected in the cyclone. The size distribution of the particles remaining in the probe was estimated from data supplied by Dr. A. K. Rao.[9] The size distribution of the cyclone collection was estimated from manufacturer's information. These data was used to correct the size distribution from that available at the sampler to the actual distribution in the stack.

This technique provides for an estimate of the size distribution in the stack, but no real measure of accuracy is known. To determine the accuracy of the size distribution a complete calibration of the Andersen sampler with known size distributions and flow rates would have to be made. Since it would be nearly impossible to simulate the exact (and unknown) size distribution in the stack, it was decided to use the sampler only to show how the size distribution changes when using the various amounts of RDF with coal. Thus, the results of using the Andersen sampler in these tests show the relative changes in size distribution with RDF compared to coal, but yield only approximate results for absolute size distributions.

Table 18 is a sample data reduction form and a step-by-step procedure for the data reduction follows.

1. List the net weights for the probe, the cyclone, and the sampler stages. Determine the sum of these weights.

2. List the 50% cutoff diameters, D_{50}, for each stage at the flow rate for the test.

3. Divide the individual net weights by the total weight and multiply by 100 to yield the uncorrected percent collected, per stage. (For cases where the probe weight is not available, a modified procedure is used, as explained later.)

4. Sum the percent collected per stage cumulatively starting with the backup filter (B) and enter next to the previous stage.

5. Find the weight corrected for the cyclone losses by dividing the weight collected on each stage by the percent passing the cyclone and enter next to that stage.

6. To find the weight corrected for the probe losses, divide the weight corrected for the cyclone for each stage by the percent passing the probe and enter next to that stage.

7. Calculate the corrected percent collected per stage by dividing the weight corrected for probe losses by the total weight from step one and multiply by 100.

TABLE 18. EXAMPLE SIZING DATA REDUCTION SHEET AND DATA SET

UNIT 5 LOAD 80 RDF 0 Stage[a]	Weight collected gm	D_{50}[b] micron[b]	Uncorrected collection %/stage[c]	Uncorrected accumulation % < D_{50}	Cyclone pass[d] (%)	Weight corrected for cyclone gm	Probe pass[e] (%)	Weight corrected for probe gm	Corrected collection[f] %/stage	Corrected accumulation % < D_{50}
Q = 11.02 N ℓ/min		V_{ms} = 220 N ℓ								
Probe	0.3338		62.07	37.93		0.3338				
Cyclone	0.0179		3.33	34.60						
0	0.0023	16.8	0.43	34.17	5	0.0460	10	0.2478	46.09	53.91
1	0.0043	10.8	0.80	33.37	18	0.0239	33	0.0724	13.46	40.45
2	0.0177	6.8	3.29	30.08	71	0.0249	61	0.0408	7.59	32.86
3	0.0187	7.8	3.48	26.60	88	0.0213	76	0.0280	5.21	27.65
4	0.0103	3.05	1.92	24.68	97	0.0106	90	0.0118	2.19	25.46
5	0.0107	1.55	1.99	22.69	98	0.0109	97	0.0112	2.08	23.38
6	0.0111	0.96	2.06	20.63	98	0.0113	> 99	0.0116	2.12	21.26
7	0.0395	0.67	7.35	13.28	98	0.0403	> 99	0.0407	7.57	13.69
F	0.0714	0	13.28	0	98	0.0729	> 99	0.0736	13.69	0
Total	0.5377									
Q = 10.79 N ℓ/min		V_{ms} = 213 N ℓ								
Probe	(0.3075)*		(66.0)	34.01		0.2376				
Cyclone	0.0019		0.41	33.60		-				
0	0.0039	17.0	0.84	32.76	5	0.0780	6	0.2270	48.72	51.28
1	0.0036	11.0	0.77	31.99	18	0.0200	30	0.0667	14.32	36.96
2	0.0075	7.0	1.61	30.38	70	0.0107	58	0.0185	3.97	32.99
3	0.0146	4.93	3.13	27.25	89	0.0164	78	0.0210	4.51	28.48
4	0.0149	3.13	3.20	24.05	97	0.0154	90	0.0171	3.67	24.81
5	0.0106	1.6	2.28	21.77	98	0.0108	97	0.0112	2.40	22.41
6	0.0107	0.96	2.30	19.47	98	0.0109	> 99	0.0110	2.36	20.05
7	0.0306	0.69	6.57	12.90	98	0.0312	> 99	0.0315	6.76	13.29
F	0.0601	0	12.90	0	98	0.0613	> 99	0.619	13.29	0
Total	(0.4659)									

[a] Andersen stages and plates are not coincident. The probe includes everything ahead of the cyclone. The cyclone includes everything from the entrance to the cyclone up to and including the "0" plate. Stage "0" corresponds to plate "1", stage "1" to plate "2", etc., and "F" indicates the back-up filter stage.

[b] Aerodynamic 50% cutoff diameter (D_{50}) from manufacturer's supplied calibration based on flow rate.

[c] As collected weight percent each stage based on 100% equals sum of collection for all stages plus the probe and cyclone.

[d] Percent of D_{50} which will pass through the cyclone. From manufacturer supplied data.

[e] Percent of D_{50} which will pass through the probe into the cyclone. From reference.

[f] Based on 100% equals the sum of the actual weights collected on all stages, the probe, and the cyclone.

* No probe weight. Probe weight set at 66% total.

8. Calculate the corrected cumulative percent less than D_{50} for any stage by summing the corrected percent per plate cumulatively starting with the backup filter and entering next to the previous stage.

In cases where the probe weight was unavailable or incorrect, the average probe weight percent was used to compute a probable probe weight. Particulate collected in the probe may be lost during handling, transportation from the site to the laboratory, and when rinsing out the particulate. All valid probe weights were averaged and yielded a value of 66% collection in the probe. An overall average was used to accommodate all possible trends for individual load and RDF combinations. The weight of the probe collection was calculated from this value. The weight of the stage collection plus the cyclone collection was 34% of the total. The total weight is then the stage collection plus the cyclone divided by 0.34. The probe collection is 0.66 times this total. This total based on 66% collection in the probe was used for all further calculations for these special cases.

Appendix K contains the tabulation of results from the Andersen sampler for the experimental runs of this study.

Figures 20 and 21 show the average particle size distributions for all tests performed on boiler unit Nos. 5 and 6, respectively. The horizontal bars represent variations of one standard deviation on each side of the average cumulative percent less than D_{50}. From these plots, the average size distribution on unit No. 6 at 80% load is shifted toward the larger sizes (lesser amount of smaller sizes accumulated) than the average size distribution on unit No. 5 at the combined 60, 80, and 100% loads.

Figure 22 shows the average size distributions for all tests performed on boiler unit Nos. 5 and 6 at the nominal values of rated steam load of 60, 80, and 100%. Each data point on this plot generally represents the average of three experimental runs. This plot shows the size distribution shifting on unit No. 5 first to smaller particles as the boiler load increases from 60 to 80%, then shifting to larger particles as the boiler load increases from 80 to 100%. The 100% load size distribution is shifted to the larger sizes as compared to the 60% load condition. This variation in size distribution appears to be in concert with the variation in efficiency of the multiclone particulate collectors. Collector efficiency increases (e.g., recall Figures 16 and 17). At or near the 80% boiler load, more of the larger particles are separated from the flow. The collector efficiency drops in moving from the approximate 80% load condition to either the 60 or 100% load condition, thus, allowing more of the larger particles through the collector. A comparison of size distributions at the 80% load condition for boiler unit Nos. 5 and 6 is also shown in Figure 22. Boiler unit No. 6 and its collector have a size distribution containing less of the smaller sizes than boiler unit No. 5. This may be due to the differences in coal used in the two boilers and it may be due to slightly different configurations (manufacturer) of the collector units.

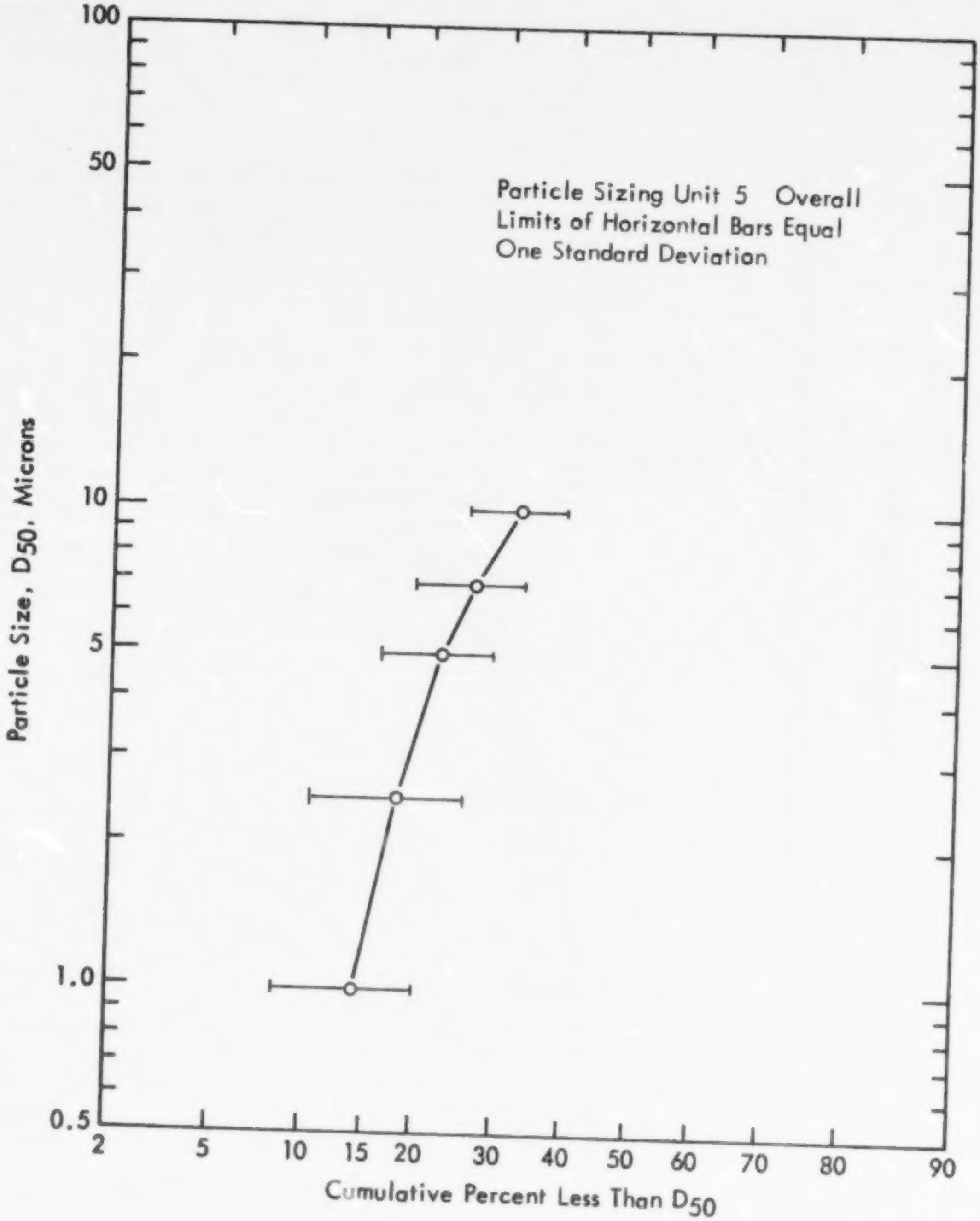


Figure 20. Overall cumulative particle size distribution of boiler unit No. 5 stack particulate emissions.

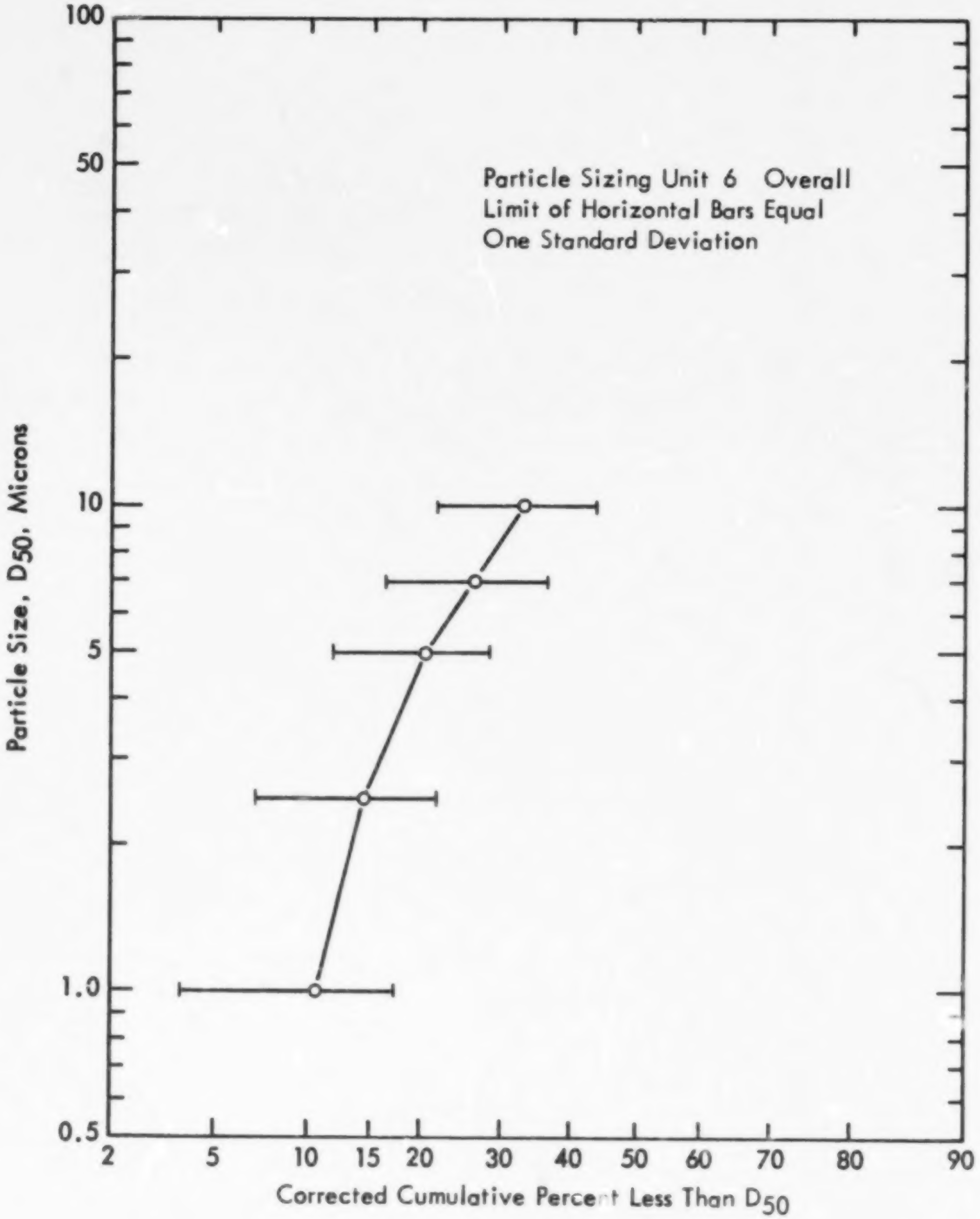


Figure 21. Overall cumulative particle size distribution of boiler unit No. 6 stack particulate emissions.

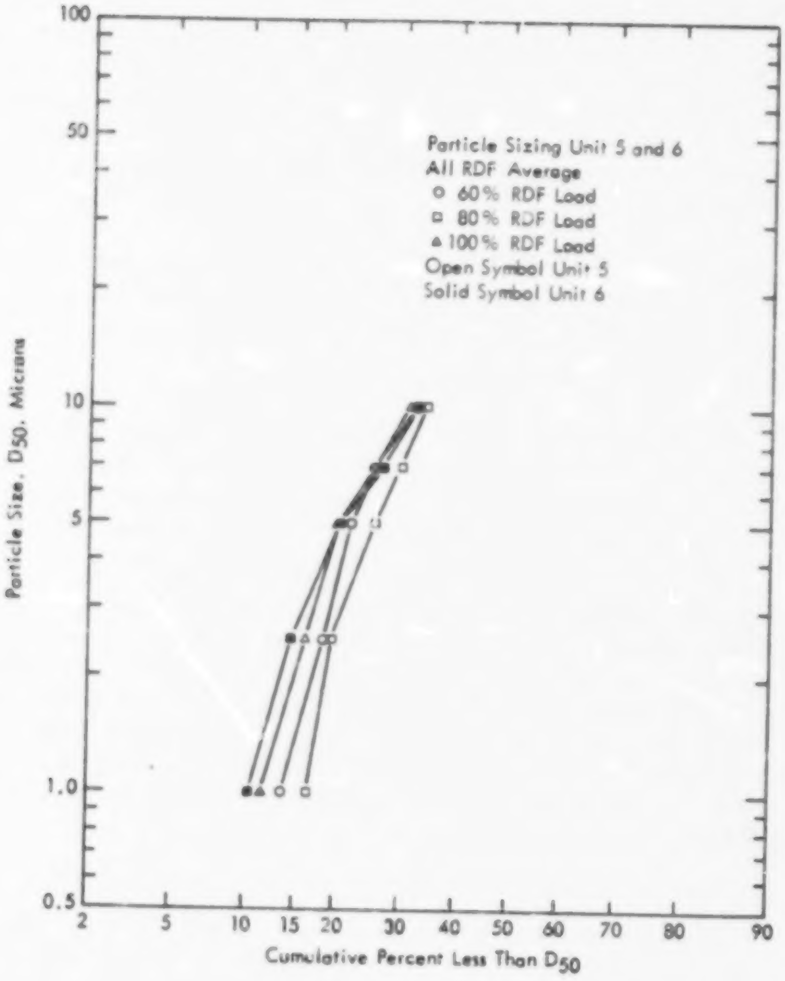


Figure 22. Cumulative particle size distribution of boiler unit Nos. 5 and 6 stack particulate emissions for differing loads.

Figures 23 and 24 show the size distribution changes as a function of RDF heat energy input to boiler unit Nos. 5 and 6, respectively. For both boiler unit Nos. 5 and 6 the size distribution shifts to a lesser percent of smaller samples as the percent RDF increases. The largest effect in this regard is at a size of 1 μ while the smallest effect is at a size of 10 μ. Figures 25, 26, and 27 illustrate the information contained in Figures 23 and 24 as a function of particle size. The straight lines on this plot represent "best" linear fits through three points by the method of least squares. At 60% load, the size distribution increases (lesser percent of small particles accumulated) with percent RDF. At 80% load, the shift in size distribution is small and not as dramatic as the shift at 60% load. At 100% load, the shift occurs in the opposite direction.

Figure 28 shows the size distribution at 80% load for boiler unit No. 6 as the percent RDF increases. The trend is the same as that noted with boiler unit No. 5, and indicates the size distribution shifting slightly to the larger particles as the percent RDF increases.

Figures 29, 30, and 31 show the size distribution shifting to the larger sizes as the load increases or decreases on either side of the 80% load data points. At the 0% RDF level, the shift is larger in going from 80 to 100% than in going from 80 to 60%. The opposite is true at the 50% RDF level while the shift is about the same at the 20% RDF level.

From the above mentioned data and plots, it is evident that both boiler load and percent RDF affect the particle size distribution. Increases in load cause the distributions to increase in particle size at small percentages of RDF, but to decrease in particle size at large percentages of RDF. Increases in percent RDF cause the distributions to increase in particle size at low boiler loads, but to decrease in particle size at large boiler loads. Which effect predominates, boiler load or percent RDF, is not yet known but is being studied further.

Orsat--

The Orsat analyzer previously shown in Figure 7 was used to obtain constituents of CO_2, O_2, and N_2 in the stack and before the particulate collector. The averages of the corrected results of several samples taken during each experimental run are presented in the data matrix format in Tables 19 through 24. These results were used to determine molecular weight of the stack gas as well as to estimate excess air supplied to the boiler. Plots of excess air as a function of percent RDF heat energy input and boiler load have been previously included as Figures 18 and 19 respectively.

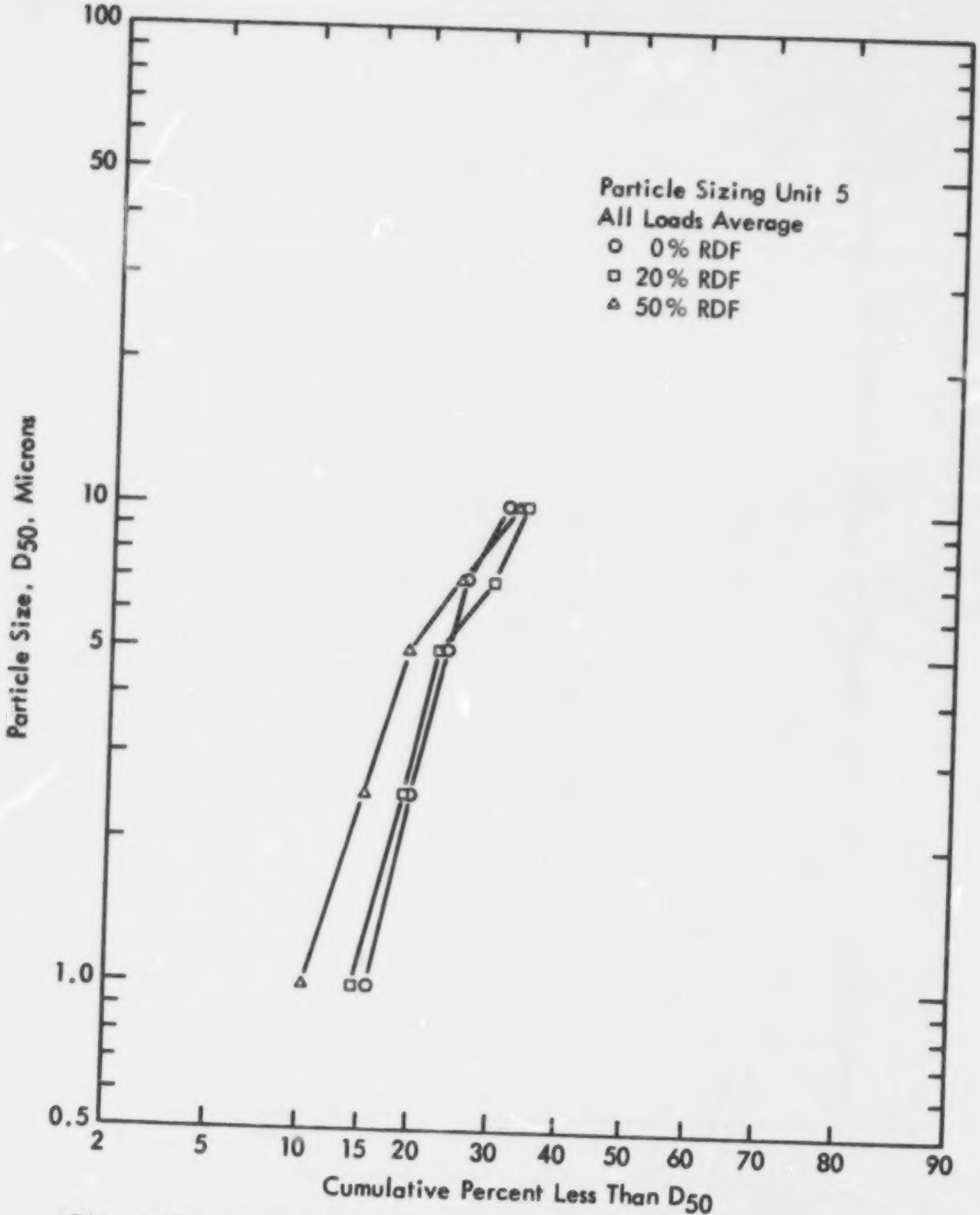


Figure 23. Cumulative particle size distribution of boiler unit stack particulate emissions for differing percent RDF.

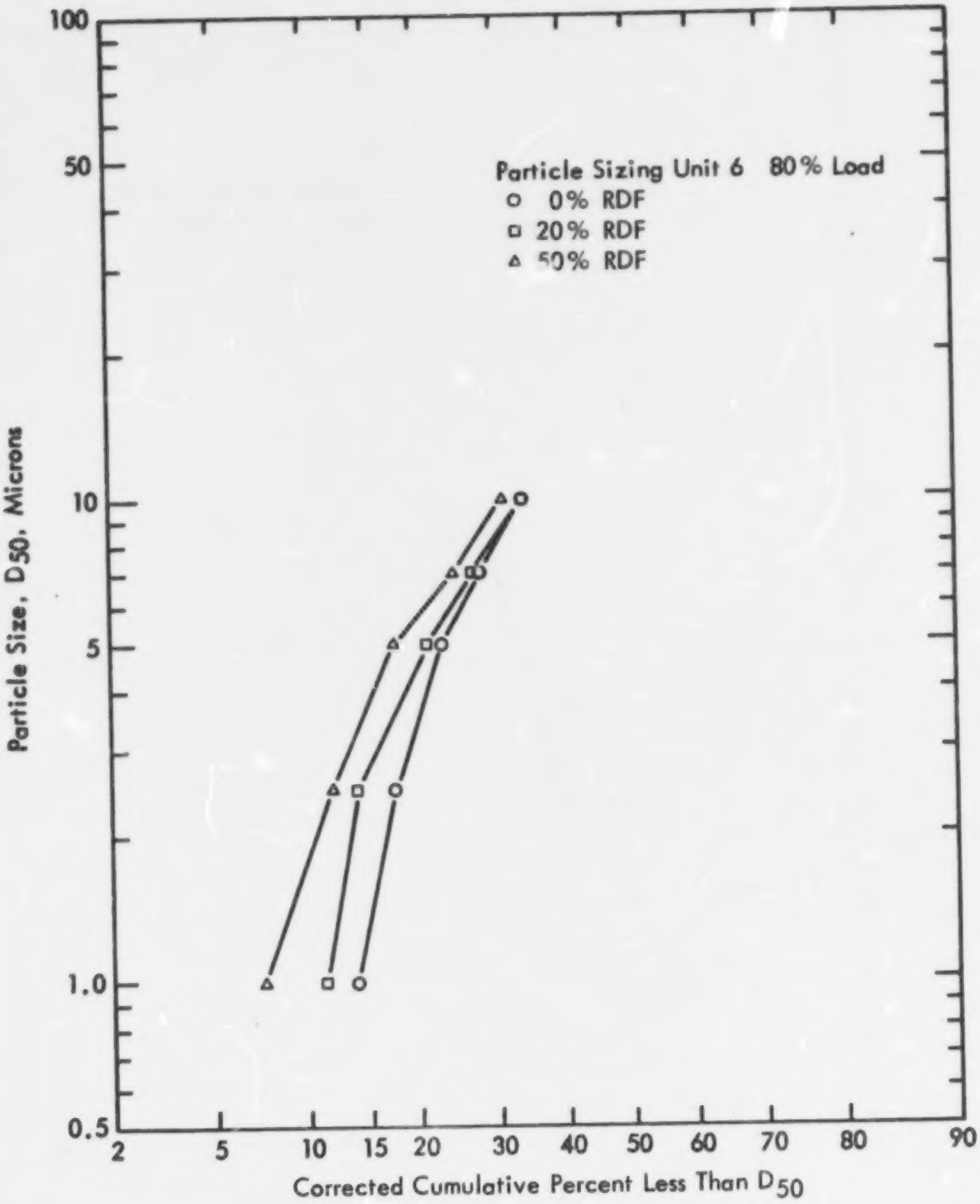


Figure 24. Cumulative particle size distribution of boiler unit No. 6 stack particulate emissions for differing percent RDF.

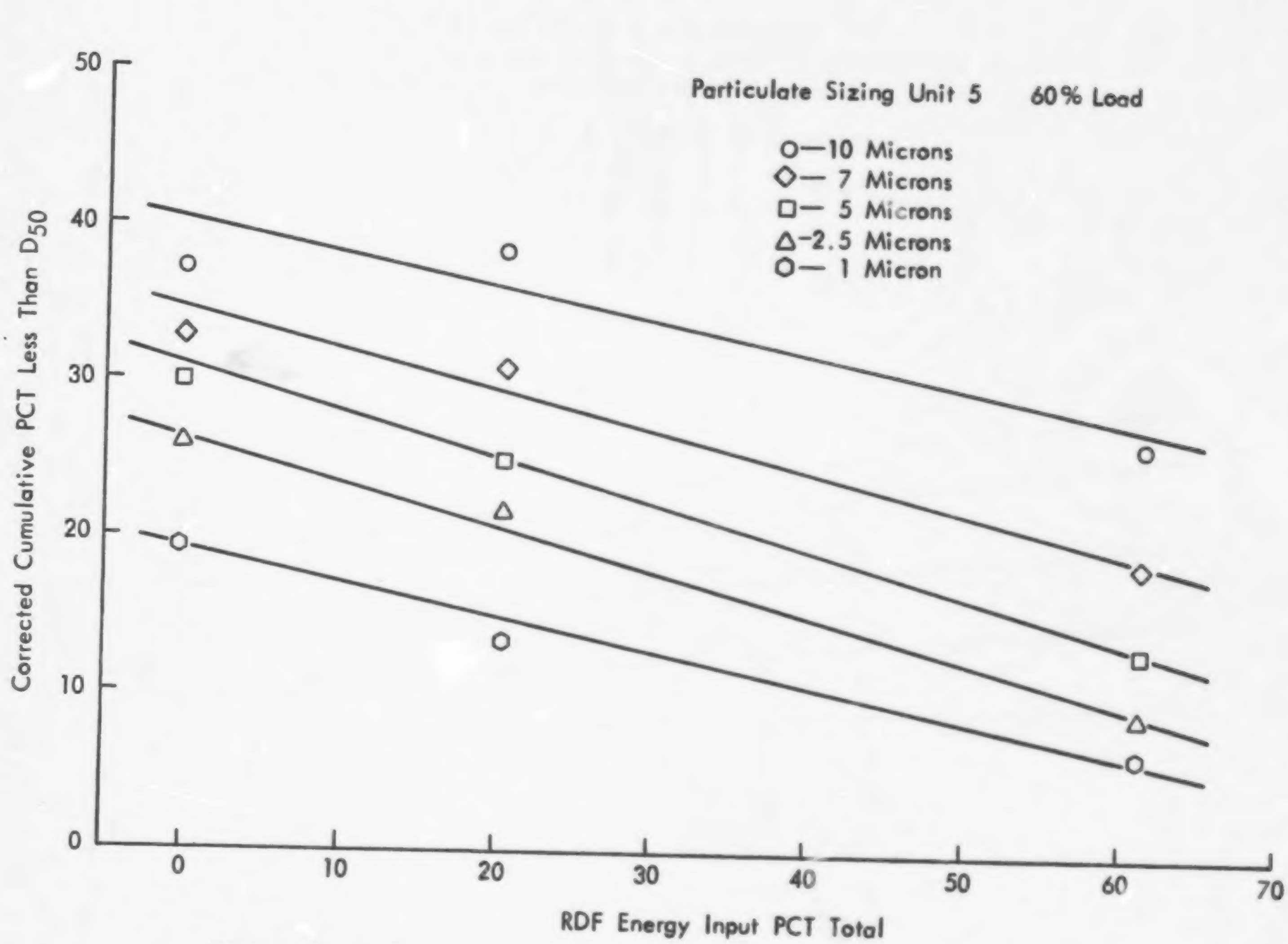


Figure 25. Corrected cumulative particle size percent less than D_{50} of boiler unit No. 5 stack particulate emissions as a function of RDF and 60% load.

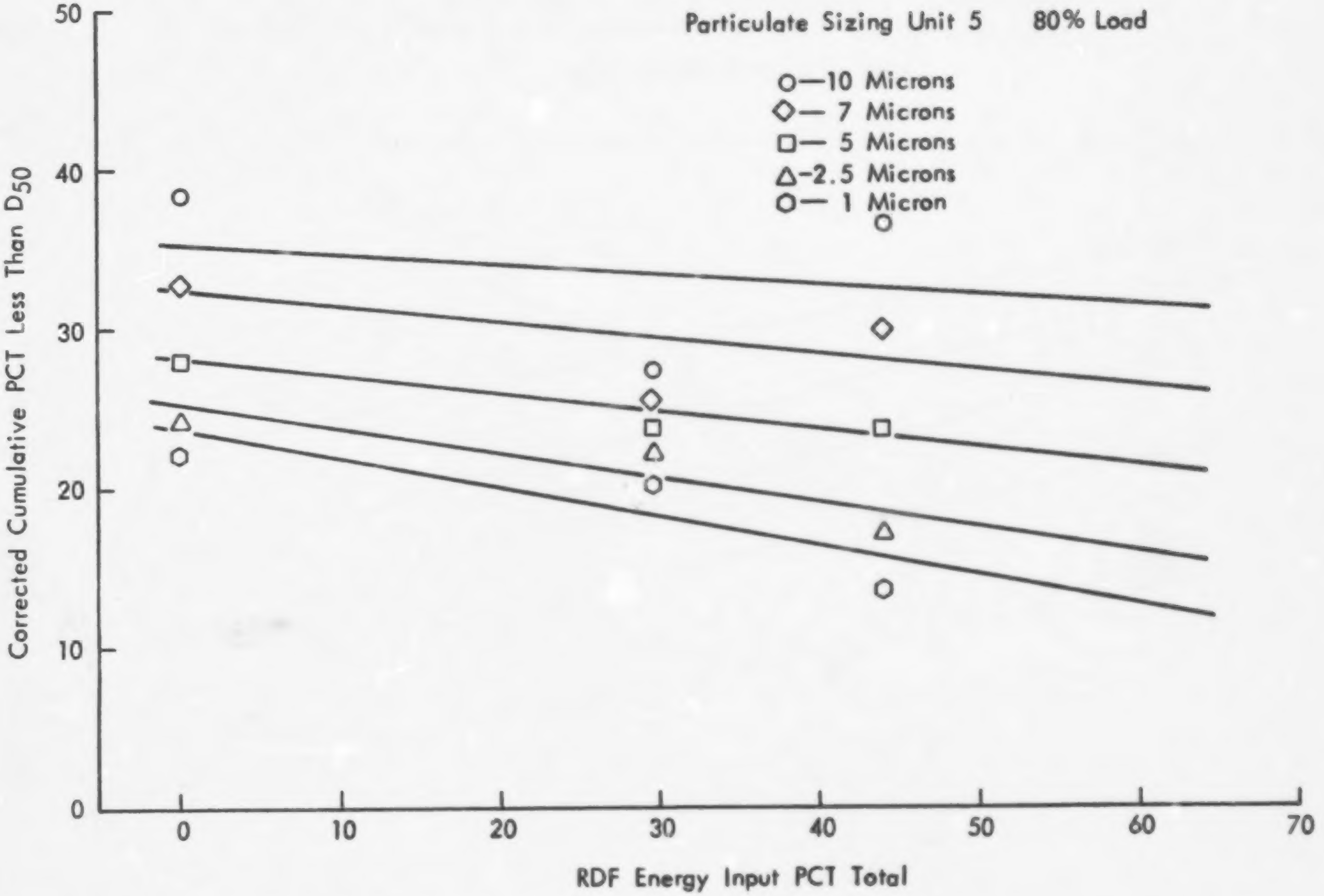


Figure 26. Corrected cumulative particle size percent less than D_{50} of boiler unit No. 5 stack particulate emissions as a function of RDF and 80% load.

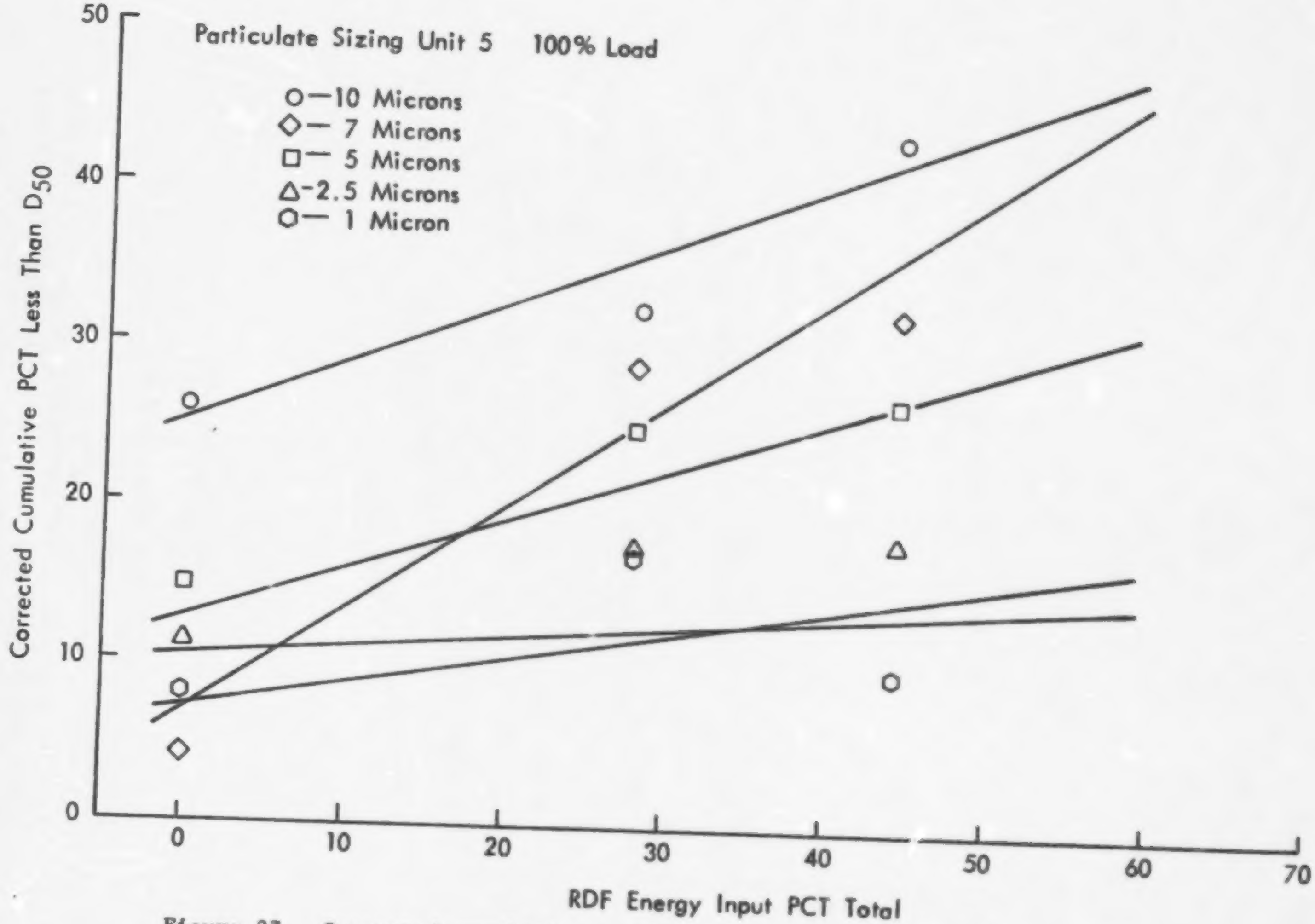


Figure 27. Corrected cumulative particle size percent less than D_{50} of boiler unit No. 5 stack particulate emissions as a function of RDF and 100% load.

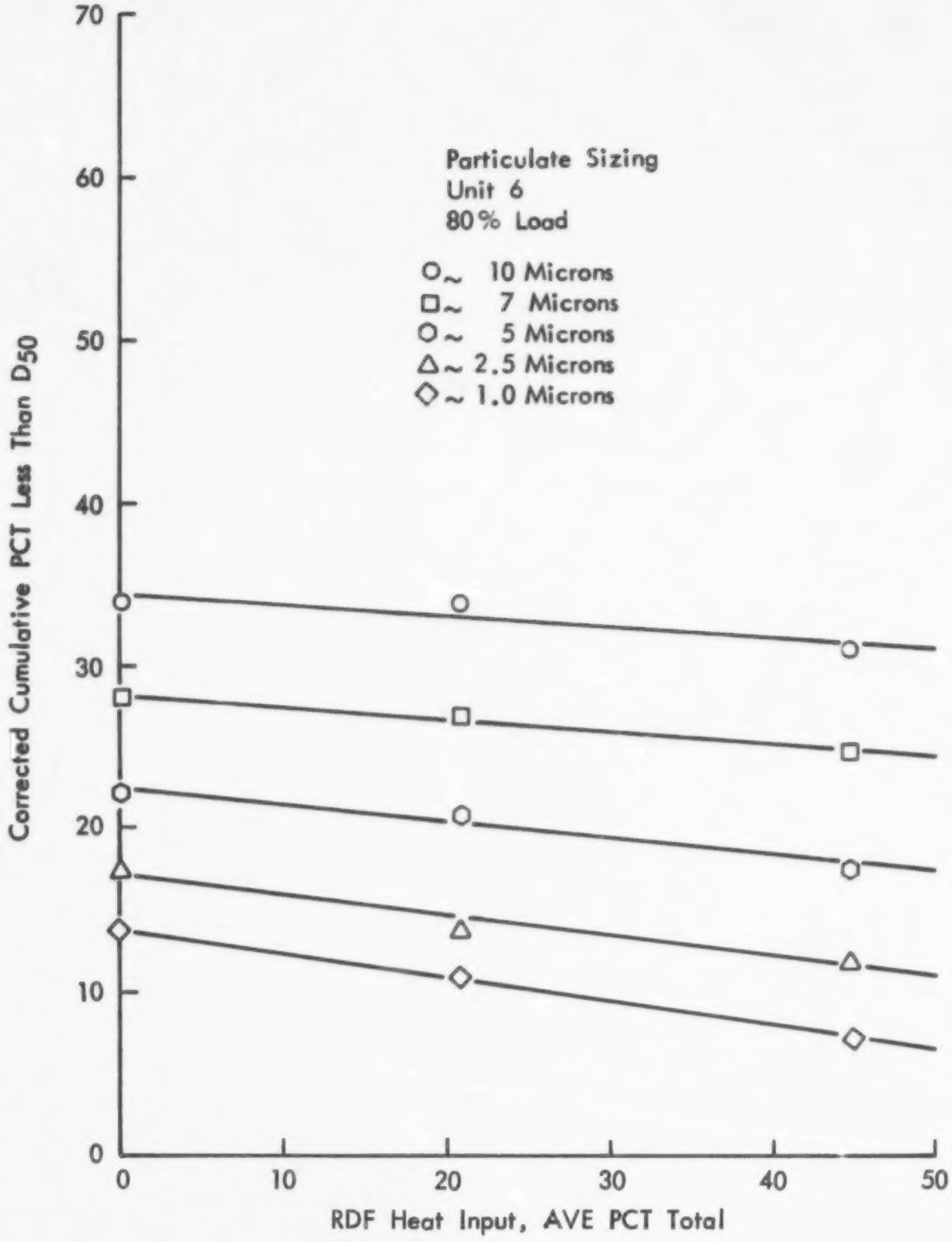


Figure 28. Corrected cumulative particle size percent less than D_{50} of boiler unit No. 6 stack particulate emissions as a function of RDF and 80% load.

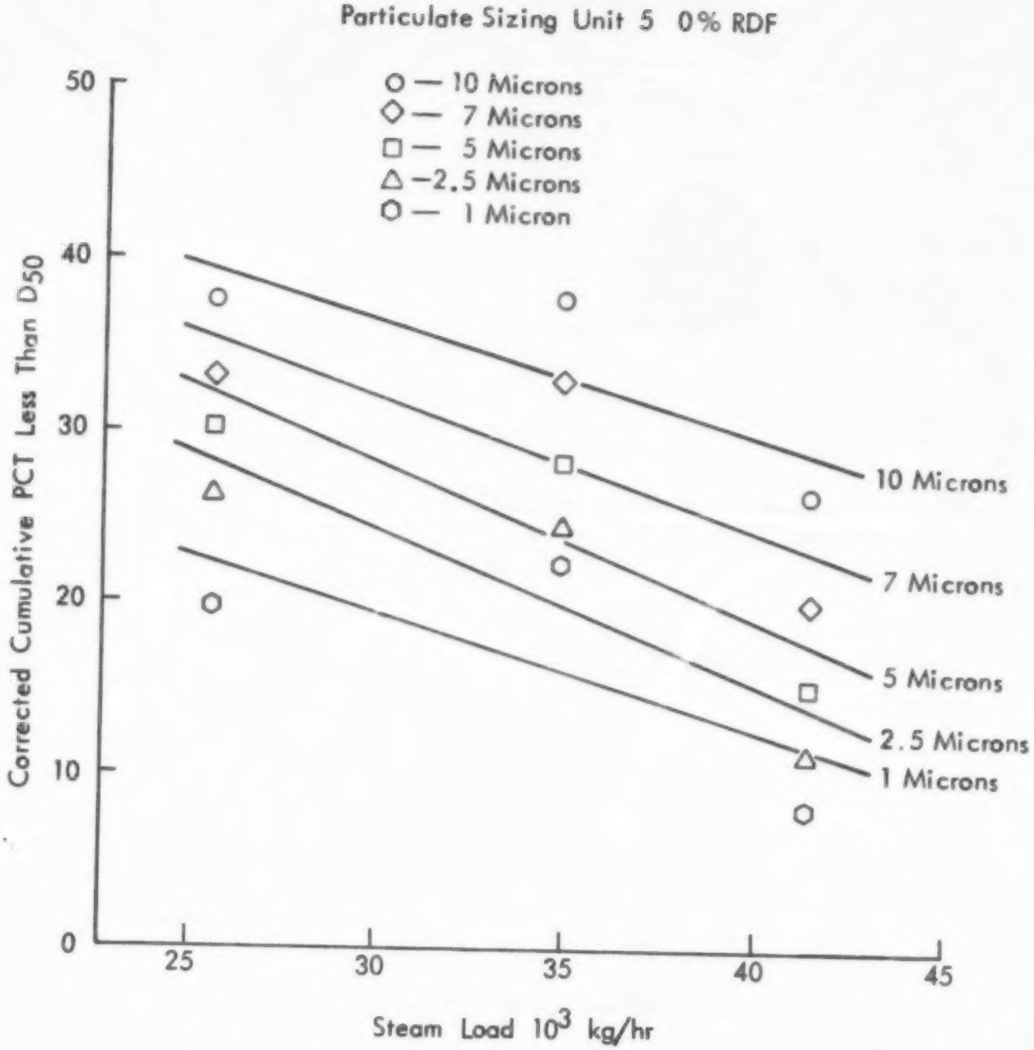


Figure 29. Corrected cumulative particle size percent less than D_{50} of boiler unit No. 5 stack particulate emissions as a function of steam load and 0% RDF.

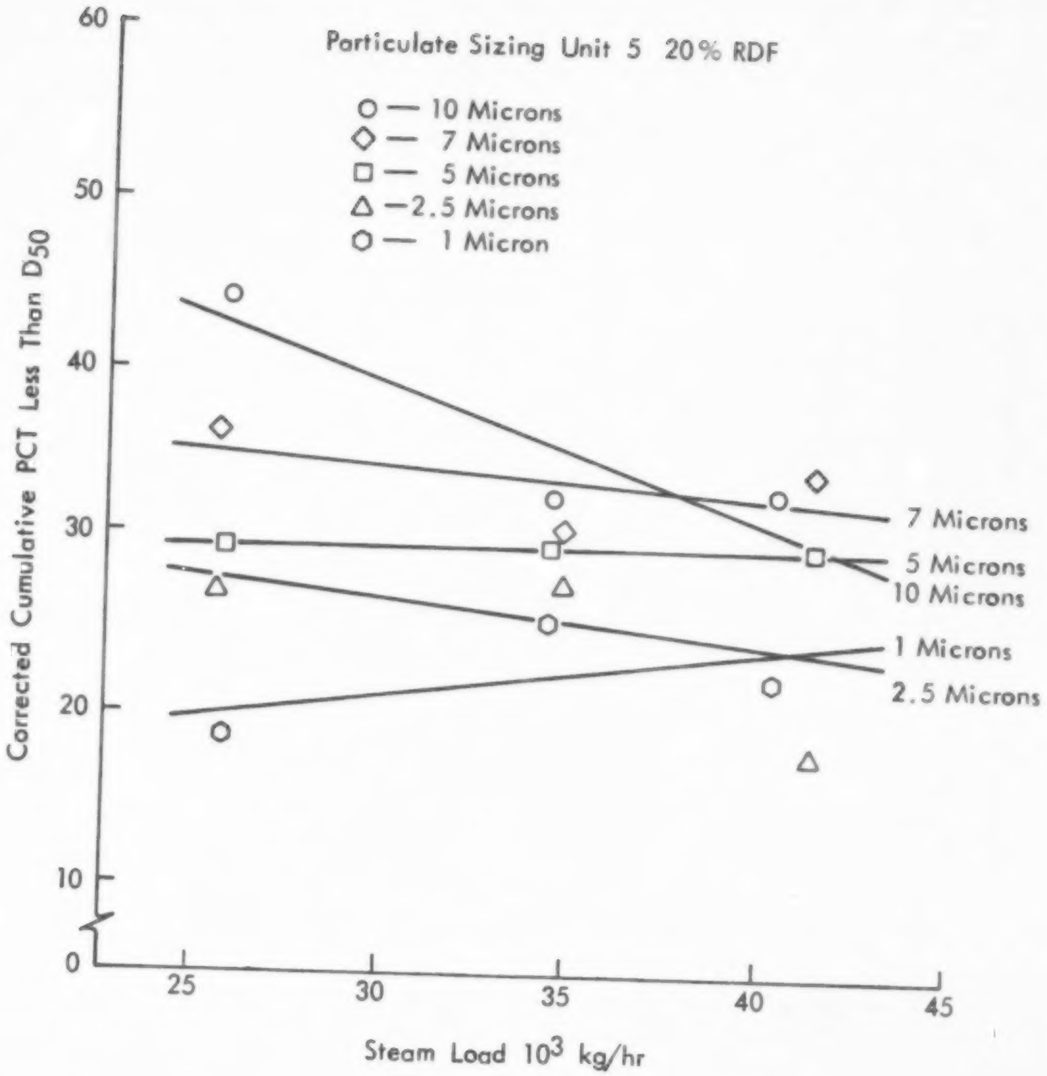


Figure 30. Corrected cumulative particle size percent less than D_{50} of boiler unit No. 5 stack particulate emissions as a function of steam load and 20% RDF.

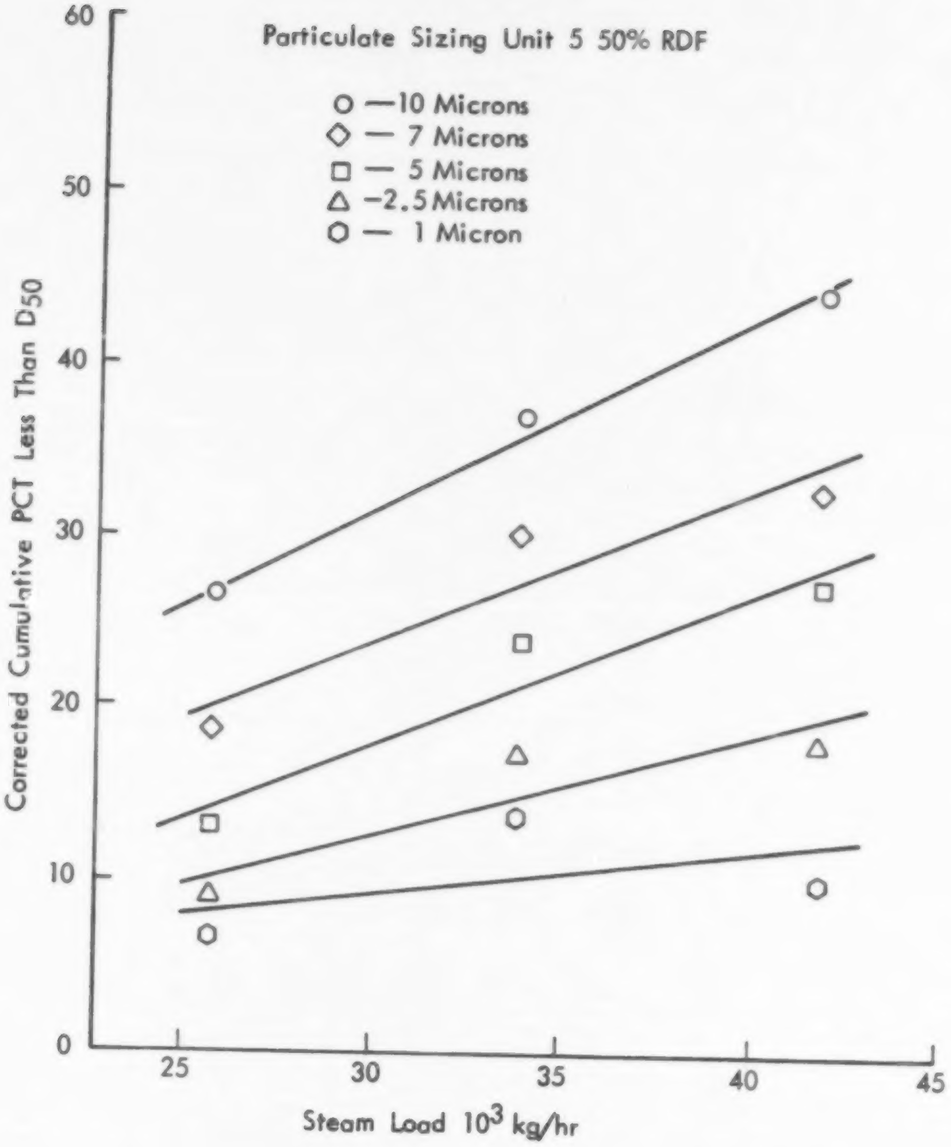


Figure 31 Corrected cumulative particle size percent less than D_{50} of boiler unit No. 5 stack particulate emissions as a function of steam load and 50% RDF.

TABLE 19. DATA MATRICES OF AVERAGE STACK ORSAT DATA FOR BOILER UNIT NO. 5

MEASURED ORSAT VALUES %CO2 STACK
BOILER NUMBER 5
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

PERCENT REFUSE	PERCENT LOAD		
	60	80	100
0	EPA# %CO2 04A 5.07E 00 04B 7.37E 00 20 8.56E 00 21 8.66E 00 35 7.91E 00 AVE 7.73E 00 SD 1.08E 00 CV 1.39E-01	EPA# %CO2 05 7.91E 00 16 7.50E 00 17 8.09E 00 AVE 7.83E 00 SD 3.02E-01 CV 3.86E-02	EPA# %CO2 11 1.05E 01 31 9.78E 00 32 9.97E 00 AVE 1.01E 01 SD 3.82E-01 CV 3.78E-02
20	EPA# %CO2 04 8.56E 00 09A 7.00E 00 09B 7.08E 00 33 7.68E 00 AVE 7.38E 00 SD 4.61E-01 CV 5.51E-02	EPA# %CO2 06 7.69E 00 12 8.69E 00 13 9.08E 00 AVE 8.48E 00 SD 7.10E-01 CV 8.38E-02	EPA# %CO2 07 9.36E 00 14 1.08E 01 19 1.19E 01 AVE 1.07E 01 SD 1.29E 00 CV 1.21E-01
50	EPA# %CO2 01 7.20E 00 34 7.74E 00 35 7.81E 00 AVE 7.58E 00 SD 3.34E-01 CV 4.41E-02	EPA# %CO2 02 8.88E 00 10 7.81E 00 15 7.66E 00 AVE 8.12E 00 SD 6.65E-01 CV 8.19E-02	EPA# %CO2 03S 7.95E 00 18 1.15E 01 AVE 9.72E 00 SD 2.50E 00 CV 2.57E-01
0	EPA# %O2 04A 8.40E 00 04B 9.53E 00 20 1.05E 01 21 1.05E 01 35 1.06E 01 AVE 9.91E 00 SD 9.49E-01 CV 9.57E-02	EPA# %O2 05 8.44E 00 16 1.18E 01 17 1.08E 01 AVE 1.03E 01 SD 1.73E 00 CV 1.68E-01	EPA# %O2 11 7.47E 00 31 8.47E 00 32 8.75E 00 AVE 8.23E 00 SD 6.74E-01 CV 8.19E-02
20	EPA# %O2 04 9.59E 00 09A 8.44E 00 09B 1.20E 01 33 1.11E 01 AVE 1.03E 01 SD 1.60E 00 CV 1.55E-01	EPA# %O2 06 8.63E 00 12 9.93E 00 13 9.60E 00 AVE 9.39E 00 SD 6.77E-01 CV 7.21E-02	EPA# %O2 07 7.16E 00 14 6.37E 00 19 6.18E 00 AVE 6.57E 00 SD 5.20E-01 CV 7.92E-02
50	EPA# %O2 01 1.14E 01 34 1.06E 01 35 1.08E 01 AVE 1.10E 01 SD 4.26E-01 CV 3.88E-02	EPA# %O2 02 9.32E 00 10 9.45E 00 15 8.52E 00 AVE 9.10E 00 SD 5.04E-01 CV 5.54E-02	EPA# %O2 03S 8.85E 00 18 6.60E 00 AVE 7.72E 00 SD 1.59E 00 CV 2.06E-01
0	EPA# %N2 04A 8.55E 01 04B 8.31E 01 20 8.08E 01 21 8.08E 01 35 8.15E 01 AVE 8.24E 01 SD 2.00E 00 CV 2.43E-02	EPA# %N2 05 8.36E 01 16 8.07E 01 17 8.12E 01 AVE 8.18E 01 SD 1.60E 00 CV 1.96E-02	EPA# %N2 11 8.20E 01 31 8.18E 01 32 8.13E 01 AVE 8.17E 01 SD 3.78E-01 CV 4.62E-03
20	EPA# %N2 04 8.39E 01 09A 8.46E 01 09B 8.09E 01 33 8.12E 01 AVE 8.26E 01 SD 1.86E 00 CV 2.25E-02	EPA# %N2 06 8.37E 01 12 8.14E 01 13 8.13E 01 AVE 8.21E 01 SD 1.34E 00 CV 1.64E-02	EPA# %N2 07 8.35E 01 14 8.29E 01 19 8.19E 01 AVE 8.28E 01 SD 7.98E-01 CV 9.64E-03
50	EPA# %N2 01 8.14E 01 34 8.16E 01 35 8.14E 01 AVE 8.14E 01 SD 1.47E-01 CV 1.80E-03	EPA# %N2 02 8.18E 01 10 8.26E 01 15 8.38E 01 AVE 8.28E 01 SD 1.02E 00 CV 1.23E-02	EPA# %N2 03S 8.32E 01 18 8.19E 01 AVE 8.26E 01 SD 9.14E-01 CV 1.11E-02

TABLE 20. DATA MATRICES OF AVERAGE STACK ORSAT DATA FOR BOILER UNIT NO. 6

MEASURED ORSAT VALUES %CO2 STACK
BOILER NUMBER 6
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

PERCENT REFUSE	PERCENT LOAD 60	80	100
0	EPA# %CO2	EPA# %CO2 24 8.56E 00 29 9.67E 00 30 1.19E 01 AVE 1.01E 01 SD 1.33E 00 CV 1.33E-01	EPA# %CO2
20	EPA# %CO2	EPA# %CO2 25 8.42E 00 26 8.10E 00 27 7.79E 00 AVE 8.10E 00 SD 3.16E-01 CV 3.90E-02	EPA# %CO2
50	EPA# %CO2	EPA# %CO2 22 9.44E 00 23 9.31E 00 28 8.81E 00 AVE 9.19E 00 SD 3.31E-01 CV 3.61E-02	EPA# %CO2
0	EPA# %O2	EPA# %O2 24 9.63E 00 29 9.00E 00 30 6.66E 00 AVE 8.43E 00 SD 1.56E 00 CV 1.85E-01	EPA# %O2
20	EPA# %O2	EPA# %O2 25 1.02E 01 26 1.08E 01 27 1.00E 01 AVE 1.03E 01 SD 3.98E-01 CV 3.70E-02	EPA# %O2
50	EPA# %O2	EPA# %O2 22 7.74E 00 23 9.76E 00 28 9.33E 00 AVE 8.95E 00 SD 1.07E 00 CV 1.20E-01	EPA# %O2
0	EPA# %N2	EPA# %N2 24 8.14E 01 29 8.13E 01 30 8.18E 01 AVE 8.15E 01 SD 2.50E-01 CV 3.07E-03	EPA# %N2
20	EPA# %N2	EPA# %N2 25 8.14E 01 26 8.11E 01 27 8.22E 01 AVE 8.16E 01 SD 5.50E-01 CV 6.74E-03	EPA# %N2
50	EPA# %N2	EPA# %N2 22 8.28E 01 23 8.09E 01 28 8.18E 01 AVE 8.18E 01 SD 9.57E-01 CV 1.17E-02	EPA# %N2

TABLE 21. DATA MATRICES OF AVERAGE ORSAT DATA BEFORE THE PARTICULATE COLLECTOR FOR BOILER UNIT NO. 5

```
MEASURED ORSAT VALUES %CO2  UPC
BOILER NUMBER 5
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

***********************************************************************
*         *                                                           *
* PERCENT *                       PERCENT LOAD                        *
*         *************************************************************
* REFUSE  *                    *                    *                 *
*         *        60          *        80          *      100        *
*         *                    *                    *                 *
***********************************************************************
*         *  EPA#    %CO2      *  EPA#    %CO2      *  EPA#    %CO2   *
*         *  04A   7.20E 00    *  05    6.80E 00    *  11   1.25E 01  *
*         *  04B   7.15E 00    *  16    7.60E 00    *  31   1.23E 01  *
*         *  20    9.13E 00    *  17    6.40E 00    *  32   9.60E 00  *
*         *  21    1.08E 01    *                    *                 *
*         *  35    9.23E 00    *                    *                 *
*    0    *                    *                    *                 *
*         *  AVE   8.51E 00    *  AVE   6.93E 00    *  AVE  1.15E 01  *
*         *   SD   1.53E 00    *   SD   6.11E-01    *   SD  1.64E 00  *
*         *   CV   1.80E-01    *   CV   8.81E-02    *   CV  1.43E-01  *
***********************************************************************
*         *  EPA#    %CO2      *  EPA#    %CO2      *  EPA#    %CO2   *
*         *  04A   7.03E 00    *  06    6.67E 00    *  07   8.85E 00  *
*         *  04B   5.88E 00    *  12    8.03E 00    *  14   8.80E 00  *
*         *  33    7.35E 00    *  13    8.86E 00    *  19   1.02E 01  *
*         *                    *                    *                 *
*   20    *                    *                    *                 *
*         *  AVE   6.74E 00    *  AVE   7.85E 00    *  AVE  9.29E 00  *
*         *   SD   7.98E-01    *   SD   1.11E 00    *   SD  8.12E-01  *
*         *   CV   1.18E-01    *   CV   1.41E-01    *   CV  8.73E-02  *
***********************************************************************
*         *  EPA#    %CO2      *  EPA#    %CO2      *  EPA#    %CO2   *
*         *  01    5.93E 00    *  02    8.51E 00    *  18   8.66E 00  *
*         *  34    7.09E 00    *  10    9.13E 00    *                 *
*         *  35    7.73E 00    *  15    7.77E 00    *                 *
*         *                    *                    *                 *
*   50    *                    *                    *                 *
*         *  AVE   6.91E 00    *  AVE   8.47E 00    *  AVE  8.66E 00  *
*         *   SD   9.10E-01    *   SD   6.79E-01    *   SD  0.00E-01  *
*         *   CV   1.32E-01    *   CV   8.01E-02    *   CV  0.00E-01  *
***********************************************************************
*         *  EPA#    %O2       *  EPA#    %O2       *  EPA#    %O2    *
*         *  04A   1.01E 01    *  05    1.04E 01    *  11   6.00E 00  *
*         *  04B   8.10E 00    *  16    1.14E 01    *  31   5.56E 00  *
*         *  20    1.02E 01    *  17    1.28E 01    *  32   9.49E 00  *
*         *  21    9.70E 00    *                    *                 *
*         *  35    1.04E 01    *                    *                 *
*    0    *                    *                    *                 *
*         *  AVE   9.72E 00    *  AVE   1.15E 01    *  AVE  7.01E 00  *
*         *   SD   9.79E-01    *   SD   1.18E 00    *   SD  2.15E 00  *
*         *   CV   9.98E-02    *   CV   1.00E-01    *   CV  3.07E-01  *
***********************************************************************
*         *  EPA#    %O2       *  EPA#    %O2       *  EPA#    %O2    *
*         *  04A   1.14E 01    *  06    1.21E 01    *  07   9.31E 00  *
*         *  04B   1.33E 01    *  12    1.09E 01    *  14   1.05E 01  *
*         *  33    1.16E 01    *  13    9.37E 00    *  19   8.05E 00  *
*         *                    *                    *                 *
*   20    *                    *                    *                 *
*         *  AVE   1.21E 01    *  AVE   1.07E 01    *  AVE  9.27E 00  *
*         *   SD   1.07E 00    *   SD   1.40E 00    *   SD  1.20E 00  *
*         *   CV   8.82E-02    *   CV   1.31E-01    *   CV  1.30E-01  *
***********************************************************************
*         *  EPA#    %O2       *  EPA#    %O2       *  EPA#    %O2    *
*         *  01    1.16E 01    *  02    9.49E 00    *  18   1.11E 01  *
*         *  34    1.17E 01    *  10    9.54E 00    *                 *
*         *  35    1.15E 01    *  15    1.12E 01    *                 *
*         *                    *                    *                 *
*   50    *                    *                    *                 *
*         *  AVE   1.16E 01    *  AVE   1.02E 01    *  AVE  1.11E 01  *
*         *   SD   9.63E-02    *   SD   8.74E-01    *   SD  0.00E-01  *
*         *   CV   8.30E-03    *   CV   8.57E-02    *   CV  0.00E-01  *
***********************************************************************
*         *  EPA#    %N2       *  EPA#    %N2       *  EPA#    %N2    *
*         *  04A   8.28E 01    *  05    8.28E 01    *  11   8.15E 01  *
*         *  04B   8.38E 01    *  16    8.09E 01    *  31   8.21E 01  *
*         *  20    8.07E 01    *  17    8.09E 01    *  32   8.09E 01  *
*         *  21    8.05E 01    *                    *                 *
*         *  35    8.09E 01    *                    *                 *
*    0    *                    *                    *                 *
*         *  AVE   8.17E 01    *  AVE   8.15E 01    *  AVE  8.15E 01  *
*         *   SD   1.46E 00    *   SD   1.07E 00    *   SD  6.03E-01  *
*         *   CV   1.79E-02    *   CV   1.32E-02    *   CV  7.40E-03  *
***********************************************************************
*         *  EPA#    %N2       *  EPA#    %N2       *  EPA#    %N2    *
*         *  04A   8.14E 01    *  06    8.12E 01    *  07   8.19E 01  *
*         *  04B   8.08E 01    *  12    8.14E 01    *  14   8.08E 01  *
*         *  33    8.13E 01    *  13    8.18E 01    *  19   8.17E 01  *
*         *                    *                    *                 *
*   20    *                    *                    *                 *
*         *  AVE   8.12E 01    *  AVE   8.15E 01    *  AVE  8.14E 01  *
*         *   SD   3.00E-01    *   SD   3.00E-01    *   SD  6.01E-01  *
*         *   CV   3.69E-03    *   CV   3.68E-03    *   CV  7.38E-03  *
***********************************************************************
*         *  EPA#    %N2       *  EPA#    %N2       *  EPA#    %N2    *
*         *  01    8.24E 01    *  02    8.20E 01    *  18   8.03E 01  *
*         *  34    8.12E 01    *  10    8.09E 01    *                 *
*         *  35    8.08E 01    *  15    8.11E 01    *                 *
*         *                    *                    *                 *
*   50    *                    *                    *                 *
*         *  AVE   8.15E 01    *  AVE   8.13E 01    *  AVE  8.03E 01  *
*         *   SD   8.63E-01    *   SD   5.86E-01    *   SD  0.00E-01  *
*         *   CV   1.06E-02    *   CV   7.21E-03    *   CV  0.00E-01  *
***********************************************************************
```

TABLE 22. DATA MATRICES OF AVERAGE ORSAT DATA BEFORE THE PARTICULATE FOR BOILER UNIT NO. 6

MEASURED ORSAT VALUES %CO2 BPC
BOILER NUMBER 6
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

PERCENT REFUSE	PERCENT LOAD		
	60	80	100
0	EPA# %CO2	EPA# %CO2 24 8.85E 00 29 7.59E 00 30 1.23E 01 AVE 9.57E 00 SD 2.42E 00 CV 2.53E-01	EPA# %CO2
20	EPA# %CO2	EPA# %CO2 25 9.33E 00 26 9.30E 00 27 1.04E 01 AVE 9.56E 00 SD 4.42E-01 CV 4.42E-02	EPA# %CO2
50	EPA# %CO2	EPA# %CO2 22 9.94E 00 23 9.11E 00 24 8.15E 00 AVE 9.06E 00 SD 8.94E-01 CV 9.86E-02	EPA# %CO2
0	EPA# %O2	EPA# %O2 24 1.08E 01 29 9.61E 00 30 5.98E 00 AVE 8.83E 00 SD 2.61E 00 CV 2.96E-01	EPA# %O2
20	EPA# %O2	EPA# %O2 25 9.85E 00 26 1.02E 01 27 7.79E 00 AVE 9.27E 00 SD 1.29E 00 CV 1.39E-01	EPA# %O2
50	EPA# %O2	EPA# %O2 22 8.71E 00 23 9.83E 00 24 1.03E 01 AVE 9.52E 00 SD 8.21E-01 CV 8.62E-02	EPA# %O2
0	EPA# %N2	EPA# %N2 24 8.08E 01 29 8.20E 01 30 8.13E 01 AVE 8.14E 01 SD 1.03E 00 CV 1.27E-02	EPA# %N2
20	EPA# %N2	EPA# %N2 25 8.08E 01 26 8.09E 01 27 8.18E 01 AVE 8.12E 01 SD 5.51E-01 CV 6.79E-03	EPA# %N2
50	EPA# %N2	EPA# %N2 22 8.14E 01 23 8.11E 01 24 8.15E 01 AVE 8.13E 01 SD 2.08E-01 CV 2.56E-03	EPA# %N2

TABLE 23. DATA MATRICES OF AVERAGE ORSAT DATA FROM ALL SAMPLE LOCATIONS ON UNIT NO. 5

AVERAGE STACK AND 3PC ORSAT VALUES %CO2
BOILER NUMBER 5
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

PERCENT REFUSE	PERCENT LOAD		
	60	80	100
0	EPA# %CO2 04A 6.63E 00 04B 7.76E 00 20 8.53E 00 21 9.74E 00 36 9.07E 00 AVE 8.14E 00 SD 1.26E 00 CV 1.55E-01	EPA# %CO2 05 7.39E 00 16 7.59E 00 17 7.29E 00 AVE 7.38E 00 SD 1.55E-01 CV 2.09E-02	EPA# %CO2 11 1.15E 01 31 1.11E 01 32 9.78E 00 AVE 1.08E 01 SD 9.03E-01 CV 8.37E-02
20	EPA# %CO2 04 5.56E 00 04A 7.02E 00 04B 6.46E 00 33 7.51E 00 AVE 6.65E 00 SD 4.94E-01 CV 7.03E-02	EPA# %CO2 06 7.18E 00 12 8.30E 00 13 9.04E 00 AVE 8.17E 00 SD 9.08E-01 CV 1.11E-01	EPA# %CO2 07 9.10E 00 14 9.78E 00 19 1.11E 01 AVE 9.99E 00 SD 1.00E 00 CV 1.01E-01
50	EPA# %CO2 01 6.56E 00 34 7.41E 00 35 7.77E 00 AVE 7.25E 00 SD 5.14E-01 CV 7.09E-02	EPA# %CO2 02 8.70E 00 10 8.47E 00 15 7.72E 00 AVE 8.30E 00 SD 5.13E-01 CV 6.18E-02	EPA# %CO2 03S 7.95E 00 18 1.01E 01 AVE 9.01E 00 SD 1.50E 00 CV 1.66E-01
0	EPA# %O2 04A 9.23E 00 04B 9.31E 00 20 1.04E 01 21 9.51E 00 36 1.07E 01 AVE 9.85E 00 SD 6.64E-01 CV 6.74E-02	EPA# %O2 05 9.64E 00 16 1.16E 01 17 1.18E 01 AVE 1.09E 01 SD 1.30E 00 CV 1.19E-01	EPA# %O2 11 6.74E 00 31 7.01E 00 32 9.12E 00 AVE 7.62E 00 SD 1.30E 00 CV 1.71E-01
20	EPA# %O2 04 8.59E 00 04A 1.00E 01 04B 1.27E 01 33 1.13E 01 AVE 1.06E 01 SD 1.39E 00 CV 1.28E-01	EPA# %O2 06 1.04E 01 12 1.02E 01 13 9.62E 00 AVE 1.01E 01 SD 4.08E-01 CV 4.05E-02	EPA# %O2 07 8.23E 00 14 8.41E 00 19 7.11E 00 AVE 7.92E 00 SD 7.03E-01 CV 8.88E-02
50	EPA# %O2 01 1.15E 01 34 1.12E 01 35 1.12E 01 AVE 1.13E 01 SD 2.18E-01 CV 1.94E-02	EPA# %O2 02 9.48E 00 10 9.69E 00 15 1.01E 01 AVE 9.76E 00 SD 3.08E-01 CV 3.16E-02	EPA# %O2 03S 8.85E 00 18 8.85E 00 AVE 8.85E 00 SD 1.03E-02 CV 1.17E-03
0	EPA# %N2 04A 8.41E 01 04B 8.38E 01 20 8.06E 01 21 8.05E 01 36 8.17E 01 AVE 8.20E 01 SD 1.65E 00 CV 2.02E-02	EPA# %N2 05 8.32E 01 16 8.08E 01 17 8.10E 01 AVE 8.17E 01 SD 1.33E 00 CV 1.63E-02	EPA# %N2 11 8.17E 01 31 8.19E 01 32 8.11E 01 AVE 8.16E 01 SD 4.38E-01 CV 5.38E-03
20	EPA# %N2 04 8.39E 01 04A 8.30E 01 04B 8.09E 01 33 8.12E 01 AVE 8.22E 01 SD 1.43E 00 CV 1.74E-02	EPA# %N2 06 8.24E 01 12 8.14E 01 13 8.14E 01 AVE 8.18E 01 SD 5.88E-01 CV 7.19E-03	EPA# %N2 07 8.27E 01 14 8.18E 01 19 8.18E 01 AVE 8.21E 01 SD 4.98E-01 CV 6.07E-03
50	EPA# %N2 01 8.19E 01 34 8.14E 01 35 8.11E 01 AVE 8.15E 01 SD 4.12E-01 CV 5.06E-03	EPA# %N2 02 8.19E 01 10 8.18E 01 15 8.21E 01 AVE 8.20E 01 SD 1.71E-01 CV 2.09E-03	EPA# %N2 03S 8.32E 01 18 8.11E 01 AVE 8.21E 01 SD 1.50E 00 CV 1.83E-02

TABLE 24. DATA MATRICES OF AVERAGE ORSAT DATA FROM ALL SAMPLE LOCATIONS ON UNIT NO.6

AVERAGE STACK AND APC ORSAT VALUES %CO2
BOILER NUMBER 6
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

PERCENT REFUSE	PERCENT LOAD 60	PERCENT LOAD 80	PERCENT LOAD 100
0	EPA# %CO2	EPA# %CO2 24 8.90E 00 29 8.63E 00 30 1.19E 01 AVE 9.81E 00 SD 1.81E 00 CV 1.85E-01	EPA# %CO2
20	EPA# %CO2	EPA# %CO2 25 8.88E 00 26 8.52E 00 27 9.09E 00 AVE 8.83E 00 SD 2.91E-01 CV 3.30E-02	EPA# %CO2
50	EPA# %CO2	EPA# %CO2 22 9.69E 00 23 9.21E 00 28 8.51E 00 AVE 9.13E 00 SD 5.92E-01 CV 6.48E-02	EPA# %CO2
0	EPA# %O2	EPA# %O2 24 1.00E 01 29 9.31E 00 30 6.27E 00 AVE 8.54E 00 SD 2.00E 00 CV 2.34E-01	EPA# %O2
20	EPA# %O2	EPA# %O2 25 1.00E 01 26 1.05E 01 27 8.90E 00 AVE 9.79E 00 SD 8.02E-01 CV 8.19E-02	EPA# %O2
50	EPA# %O2	EPA# %O2 22 8.82E 00 23 9.80E 00 28 9.82E 00 AVE 9.48E 00 SD 5.70E-01 CV 6.01E-02	EPA# %O2
0	EPA# %N2	EPA# %N2 24 8.11E 01 29 8.21E 01 30 8.18E 01 AVE 8.16E 01 SD 5.27E-01 CV 6.45E-03	EPA# %N2
20	EPA# %N2	EPA# %N2 25 8.11E 01 26 8.10E 01 27 8.20E 01 AVE 8.14E 01 SD 5.49E-01 CV 6.70E-03	EPA# %N2
50	EPA# %N2	EPA# %N2 22 8.15E 01 23 8.10E 01 28 8.17E 01 AVE 8.14E 01 SD 3.54E-01 CV 4.34E-03	EPA# %N2

Oxides of Nitrogen (NO_x)--

The results of these tests are summarized in the data matrix format of Tables 25 and 26, respectively, for boiler unit Nos. 5 and 6. The grams of NO_x emissions per megajoule of heat energy input to the boiler are plotted in Figures 32, 33, and 34, respectively, as functions of nominal RDF, nominal steam load, and excess air of the boiler. Each data point is the average of runs listed in each cell of the data matrix and usually represents the average of three experimental runs (replications). From Figure 32 it is apparent that NO_x decreases with increases above 10 to 15% nominal RDF heat energy input. This is believed to be due to decreased temperatures in the combustions chamber caused by introduction of the RDF as well as additional combustion air into the furnace section of the boiler. Figure 34 also shows that at any given load, the NO_x emissions generally decrease as the excess air increases. This figure also shows that as RDF increases NO_x decreases as already shown in Figure 32. At a particular percentage of RDF the excess air and NO_x emissions generally decrease as the load increases. The only exception to these trends is a result of the NO_x emissions at the 80% load, 0% RDF condition. Statistical analysis discussed in a following section reveals that the excess air effect predominates. Thus, the decrease in NO_x appears to be due to the additional excess air. Figure 33 indicates that the NO_x emissions generally decrease with increasing load. The trend is most dramatic for the experimental runs at the 50% nominal value of RDF.

It should also be noted that the NO_x emissions from unit No. 6 are always larger than those from unit No. 5. At 80% nominal steam load, the NO_x emissions from unit No. 6 are about 1.67 times larger on the average than the NO_x emissions from unit No. 5. The size factor between unit Nos. 5 and 6, which is about 1.31, may account for part of this difference. However, the largest factor is currently believed to be due to the different amounts of excess air available to the boilers through the RDF input lines as well as the the overfire and underfire air supplies. NO_x emissions from power plants are affected by excess air.[10,11/] Therefore, differences in NO_x may be due to the differences in excess air occurring when RDF is burned. Adjustment or normalization of the NO_x emissions for percent excess air were beyond the scope of this report.

Oxides of Sulfur (SO_x)--

The results of these tests are summarized in the data matrix format of Tables 27 and 28, respectively, for boiler unit Nos. 5 and 6. The grams of SO_x emission per megajoule of heat energy input to the boilers are plotted in Figures 35 and 36, respectively, as a function of nominal RDF heat energy input and nominal steam load of the boilers. Each plotted point of these figures represents the average of the runs listed in each cell of the data matrix and usually represents the average of three experimental runs (replications).

TABLE 25. DATA MATRIX OF NO_x EMISSIONS FOR BOILER UNIT NO. 5

```
NOX FLOW MEASURED AT THE STACK
BOILER NUMBER 5
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

*************************************************************************
*           *                                                           *
*           *                      PERCENT LOAD                         *
*  PERCENT  *                                                           *
*           *************************************************************
*  REFUSE   *                   *                   *                   *
*           *        60         *        80         *       100         *
*           *                   *                   *                   *
*************************************************************************
*           *  EPA#  (MG/MEGJ)  *  EPA#  (MG/MEGJ)  *  EPA#  (MG/MEGJ)  *
*           *  04A   1.01E 02   *  05    1.07E 02   *  11    6.26E 01   *
*           *  04B   1.01E 02   *  16    5.85E 01   *  31    9.61E 01   *
*           *  20    8.47E 01   *  17    7.37E 01   *  32    8.43E 01   *
*           *  21    9.31E 01   *                   *                   *
*           *  35    1.16E 02   *                   *                   *
*     0     *                   *                   *                   *
*           *  AVE   9.92E 01   *  AVE   7.99E 01   *  AVE   8.10E 01   *
*           *   SD   1.15E 01   *   SD   2.51E 01   *   SD   1.70E 01   *
*           *   CV   1.16E-01   *   CV   3.14E-01   *   CV   2.10E-01   *
*************************************************************************
*           *  EPA#  (MG/MEGJ)  *  EPA#  (MG/MEGJ)  *  EPA#  (MG/MEGJ)  *
*           *  03    9.80E 01   *  06    8.04E 01   *  07    7.40E 01   *
*           *  03A   1.15E 02   *  12    8.35E 01   *  14    6.11E 01   *
*           *  03B   1.03E 02   *  13    6.48E 01   *  19    9.42E 01   *
*           *  33    1.01E 02   *                   *                   *
*           *                   *                   *                   *
*    20     *                   *                   *                   *
*           *  AVE   1.04E 02   *  AVE   7.62E 01   *  AVE   7.64E 01   *
*           *   SD   7.51E 00   *   SD   1.00E 01   *   SD   1.67E 01   *
*           *   CV   7.21E-02   *   CV   1.31E-01   *   CV   2.18E-01   *
*************************************************************************
*           *  EPA#  (MG/MFGJ)  *  EPA#  (MG/MEGJ)  *  EPA#  (MG/MEGJ)  *
*           *  01    5.62E 01   *  02    5.52E 01   *  03S   5.53E 01   *
*           *  34    8.51E 01   *  10    5.46E 01   *  18    4.43E 01   *
*           *  35    9.33E 01   *  15    6.38E 01   *                   *
*           *                   *                   *                   *
*           *                   *                   *                   *
*    50     *                   *                   *                   *
*           *  AVE   7.82E 01   *  AVE   6.45E 01   *  AVE   4.98E 01   *
*           *   SD   1.95E 01   *   SD   1.67E 01   *   SD   7.78E 00   *
*           *   CV   2.49E-01   *   CV   2.59E-01   *   CV   1.56E-01   *
*************************************************************************
```

TABLE 26. DATA MATRIX OF NO_x EMISSIONS FOR BOILER UNIT NO. 6

```
NOX FLU* MEASURED AT THE STACK
BCILER NUMBER 6
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

*************************************************************************
*          *                                                            *
*          *                        PERCENT LOAD                        *
* PERCENT  *                                                            *
*          **************************************************************
* REFUSE   *                    *                    *                  *
*          *         60         *         80         *       100        *
*          *                    *                    *                  *
*************************************************************************
*          *  EPA#   (MG/MEGJ)  *  EPA#   (MG/MEGJ)  * EPA#   (MG/MEGJ) *
*          *                    *  24     1.28E 02   *                  *
*          *                    *  29     1.34E 02   *                  *
*          *                    *  30     1.39E 02   *                  *
*          *                    *                    *                  *
*    0     *                    *                    *                  *
*          *                    *  AVE    1.33E 02   *                  *
*          *                    *   SD    5.61E 00   *                  *
*          *                    *   CV    4.20E-02   *                  *
*************************************************************************
*          *  EPA#   (MG/MEGJ)  *  EPA#   (MG/MEGJ)  * EPA#   (MG/MEGJ) *
*          *                    *  25     1.27E 02   *                  *
*          *                    *  27     1.34E 02   *                  *
*          *                    *                    *                  *
*          *                    *                    *                  *
*   20     *                    *                    *                  *
*          *                    *  AVE    1.31E 02   *                  *
*          *                    *   SD    4.81E 00   *                  *
*          *                    *   CV    3.68E-02   *                  *
*************************************************************************
*          *  EPA#   (MG/MEGJ)  *  EPA#   (MG/MEGJ)  * EPA#   (MG/MEGJ) *
*          *                    *  22     1.07E 02   *                  *
*          *                    *  23     1.07E 02   *                  *
*          *                    *  28     1.03E 02   *                  *
*          *                    *                    *                  *
*   50     *                    *                    *                  *
*          *                    *  AVE    1.06E 02   *                  *
*          *                    *   SD    2.72E 00   *                  *
*          *                    *   CV    2.56E-02   *                  *
*************************************************************************
```

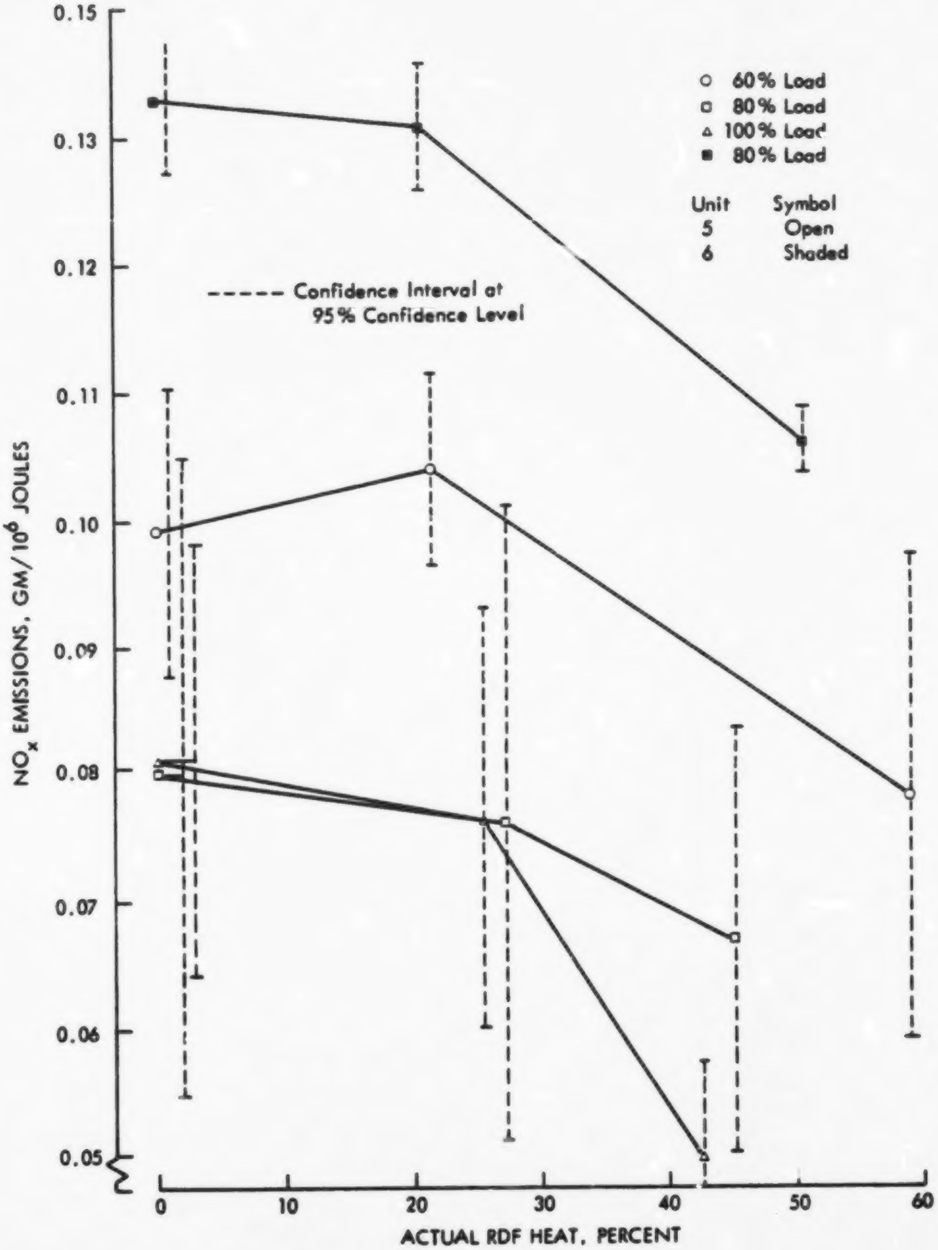


Figure 32. NO$_x$ emissions from boiler unit Nos. 5 and 6 as a function of RDF heat input.

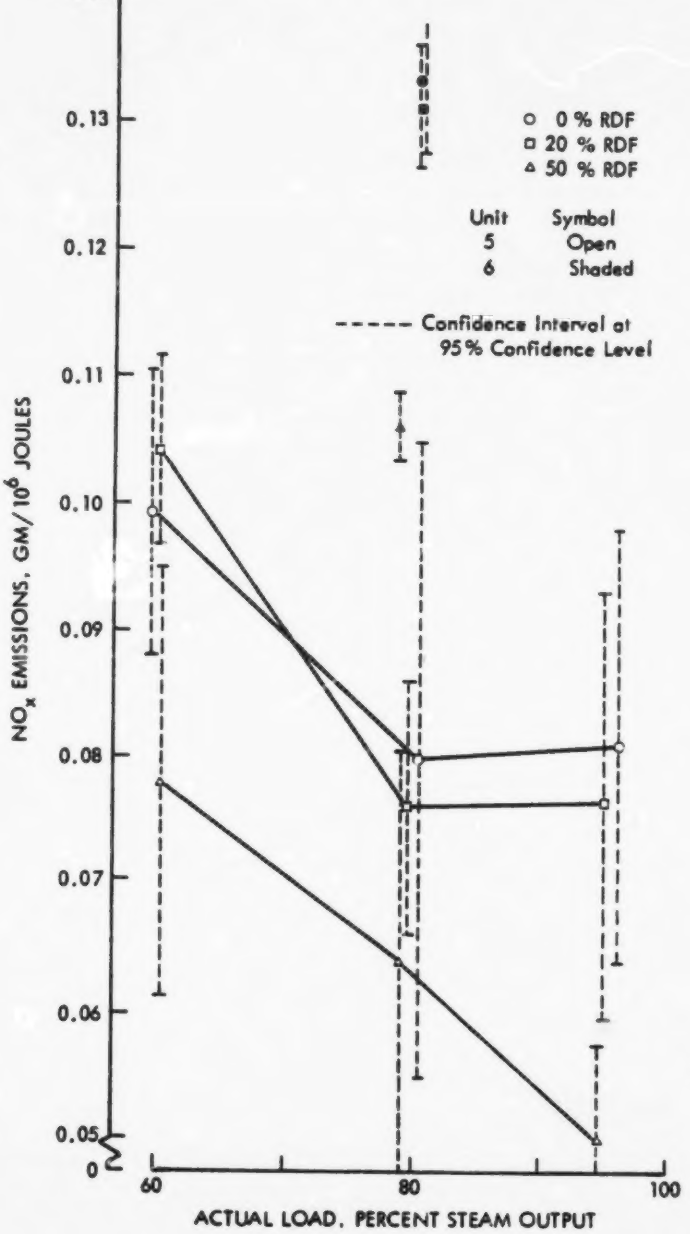


Figure 33. NO$_x$ emissions from boiler unit Nos. 5 and 6 as a function of boiler steam load.

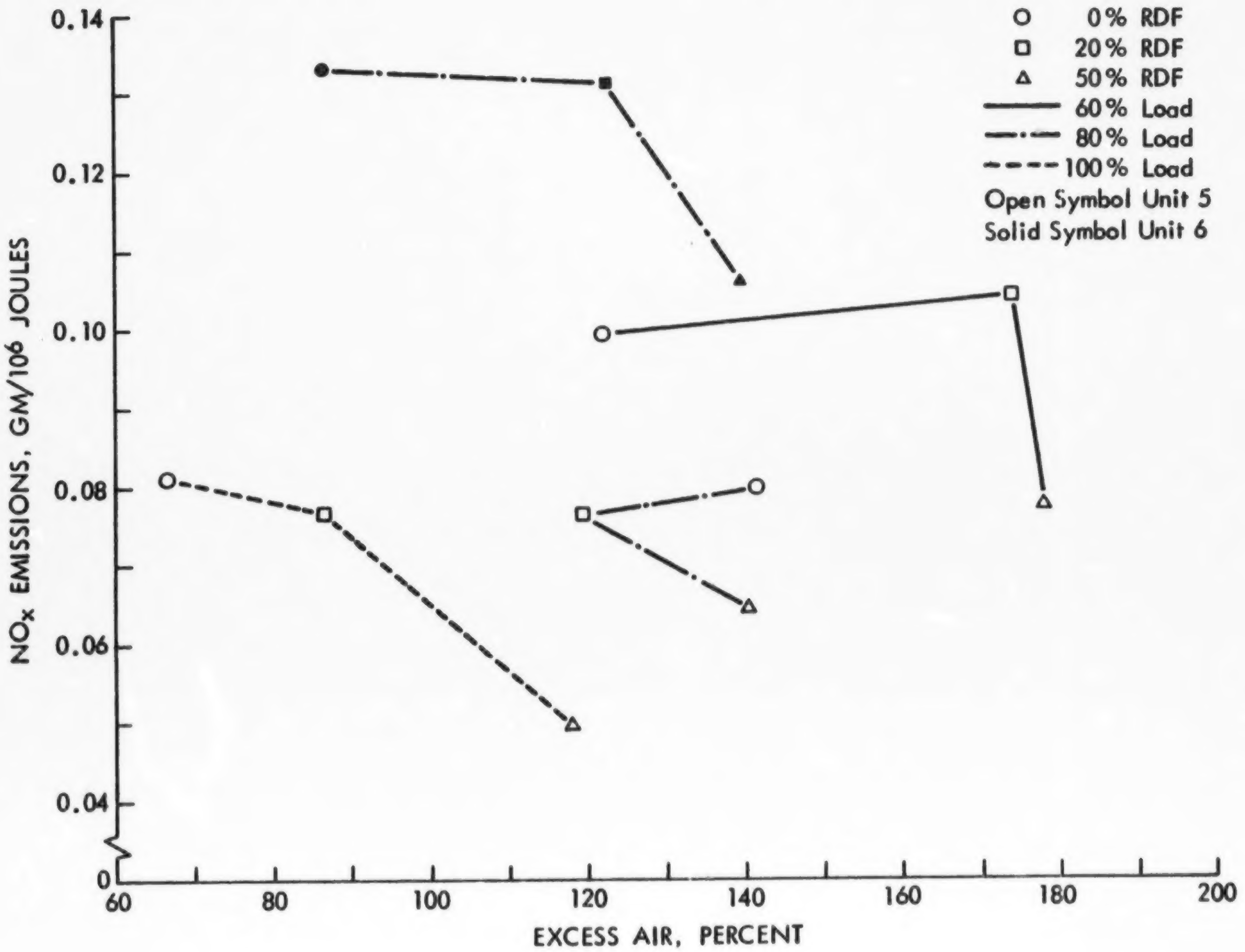


Figure 34. NO_x emissions from boiler unit Nos. 5 and 6 as a function of excess air.

TABLE 27. DATA MATRIX OF SO_x EMISSIONS FOR BOILER UNIT NO. 5

```
SOX FLOW MEASURED AT THE STACK
BOILER NUMBER 5
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

**********************************************************************
*          *                                                         *
*          *                     PERCENT LOAD                        *
* PERCENT  *                                                         *
*          ***********************************************************
* REFUSE   *                  *                  *                   *
*          *        60        *        80        *       100         *
*          *                  *                  *                   *
**********************************************************************
*          * EPA#  (MG/MEGJ) * EPA#  (MG/MEGJ)  * EPA#  (MG/MEGJ)   *
*          * 04A   3.36E 02   * 05    2.33E 03   * 11    2.39E 03    *
*          * 04B   5.29E 02   * 16    2.25E 03   *                   *
*          * 20    1.99E 03   * 17    2.28E 03   *                   *
*          * 36    2.36E 03   *                  *                   *
*          *                  *                  *                   *
*    0     *                  *                  *                   *
*          * AVE   1.30E 03   * AVE   2.29E 03   * AVE   2.39E 03    *
*          *  SD   1.02E 03   *  SD   3.86E 01   *  SD   0.00E-01    *
*          *  CV   7.82E-01   *  CV   1.69E-02   *  CV   0.00E-01    *
**********************************************************************
*          * EPA#  (MG/MEGJ) * EPA#  (MG/MEGJ)  * EPA#  (MG/MEGJ)   *
*          * 08    2.21E 03   * 06    1.69E 03   * 07    2.20E 03    *
*          * 09A   2.98E 03   * 12    1.83E 03   * 14    1.65E 03    *
*          * 09B   1.88E 03   * 13    2.07E 03   * 19    2.08E 03    *
*          * 33    2.28E 03   *                  *                   *
*          *                  *                  *                   *
*   20     *                  *                  *                   *
*          * AVE   2.34E 03   * AVE   1.86E 03   * AVE   1.98E 03    *
*          *  SD   4.59E 02   *  SD   1.94E 02   *  SD   2.90E 02    *
*          *  CV   1.96E-01   *  CV   1.04E-01   *  CV   1.47E-01    *
**********************************************************************
*          * EPA#  (MG/MEGJ) * EPA#  (MG/MEGJ)  * EPA#  (MG/MEGJ)   *
*          * 01    2.93E 02   * 02    1.58E 03   * 035   1.97E 03    *
*          * 34    9.27E 02   * 10    1.47E 03   * 18    1.50E 03    *
*          * 35    1.06E 03   * 15    1.47E 03   *                   *
*          *                  *                  *                   *
*          *                  *                  *                   *
*   50     *                  *                  *                   *
*          * AVE   7.62E 02   * AVE   1.51E 03   * AVE   1.74E 03    *
*          *  SD   4.12E 02   *  SD   6.27E 01   *  SD   3.27E 02    *
*          *  CV   5.41E-01   *  CV   4.16E-02   *  CV   1.89E-01    *
**********************************************************************
```

TABLE 28. DATA MATRIX OF SO_x EMISSIONS FOR BOILER UNIT NO. 6

```
SOX FLOW MEASURED AT THE STACK
BOILER NUMBER 6
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

*************************************************************************
*         *                                                             *
*         *                       PERCENT LOAD                          *
* PERCENT *                                                             *
*         ***************************************************************
* REFUSE  *                    *                    *                   *
*         *         60         *         80         *        100        *
*         *                    *                    *                   *
*************************************************************************
*         *  EPA#  (MG/MEGJ)   *  EPA#  (MG/MEGJ)   *  EPA#  (MG/MEGJ)  *
*         *                    *  24    1.40E 03    *                   *
*         *                    *  29    4.67E 02    *                   *
*         *                    *  30    4.38E 02    *                   *
*         *                    *                    *                   *
*         *                    *                    *                   *
*    0    *                    *                    *                   *
*         *                    *  AVE   7.69E 02    *                   *
*         *                    *   SD   5.49E 02    *                   *
*         *                    *   CV   7.14E-01    *                   *
*************************************************************************
*         *  EPA#  (MG/MEGJ)   *  EPA#  (MG/MEGJ)   *  EPA#  (MG/MEGJ)  *
*         *                    *  25    3.05E 02    *                   *
*         *                    *  27    3.47E 02    *                   *
*         *                    *                    *                   *
*         *                    *                    *                   *
*   20    *                    *                    *                   *
*         *                    *  AVE   3.26E 02    *                   *
*         *                    *   SD   2.97E 01    *                   *
*         *                    *   CV   9.11E-02    *                   *
*************************************************************************
*         *  EPA#  (MG/MEGJ)   *  EPA#  (MG/MEGJ)   *  EPA#  (MG/MEGJ)  *
*         *                    *  23    7.22E 02    *                   *
*         *                    *  28    1.46E 02    *                   *
*         *                    *                    *                   *
*         *                    *                    *                   *
*   50    *                    *                    *                   *
*         *                    *  AVE   4.34E 02    *                   *
*         *                    *   SD   4.07E 02    *                   *
*         *                    *   CV   9.38E-01    *                   *
*************************************************************************
```

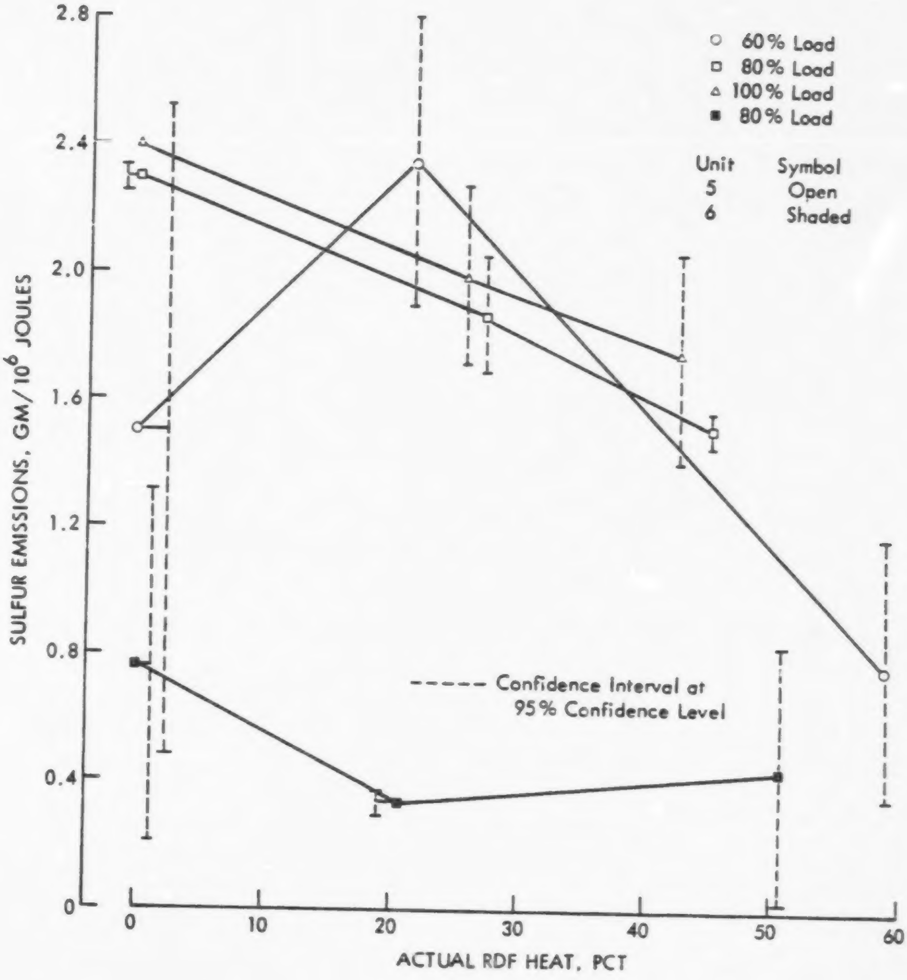


Figure 35. Sulfur emissions from boiler unit Nos. 5 and 6 as a function of RDF heat input.

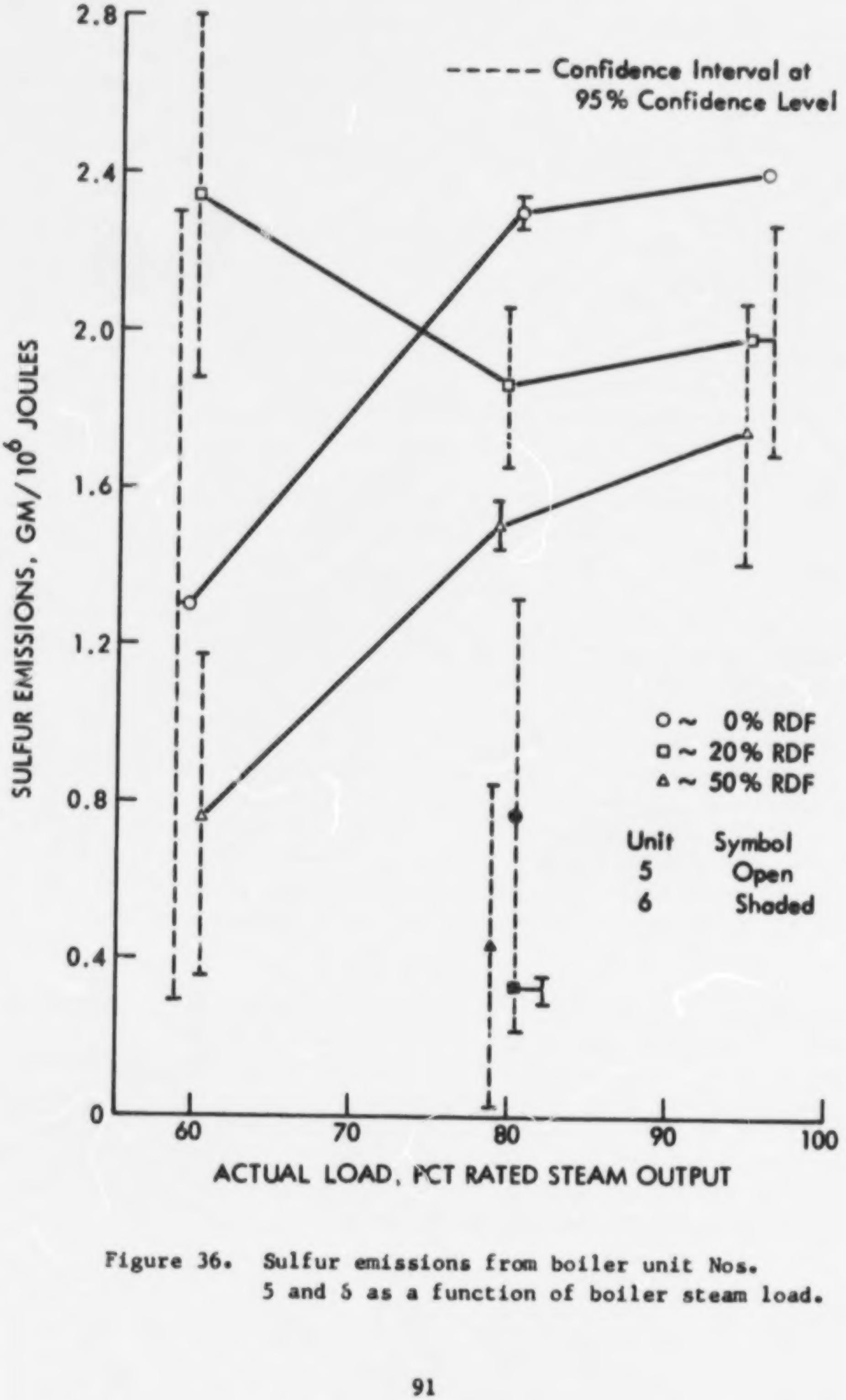


Figure 36. Sulfur emissions from boiler unit Nos. 5 and 5 as a function of boiler steam load.

From Figure 35 it appears that the general trend in sulfur dioxide emissions is to decrease with an increased amount of nominal RDF heat energy input to the boilers. The only exception to this is a single point at 60% nominal load and 20% nominal RDF heat energy input. No reason is known for this trend reversal, but it may be a peculiar operating condition of the boiler. However, from this figure one can also conclude that as load increases the sulfur dioxide emissions also increase.

It should be noted that the emissions of unit No. 5 are higher than those of unit No. 6. This is because the coal selected for unit No. 6 was a 50/50% mixture of Iowa (high sulfur) coal and Wyoming (low sulfur) coal. This coal mixture has a smaller content of sulfur than the Iowa coal used for the tests of unit No. 5. Iowa coal was selected for the tests of unit No. 5 mainly because of its high sulfur content. This was done so that the effect on sulfur emissions, due to burning RDF, which is low in sulfur content, could more readily be observed.

With the exception of the 60% load/20% RDF data point, Figure 36 shows that the sulfur dioxide emissions increase with increasing load as one would normally expect. This figure also shows that the sulfur dioxide emissions consistently decrease with corresponding increases in RDF heat energy input, as would be expected. Thus, mixing RDF with coals of relatively high sulfur content may allow some sulfur dioxide standards to be met while still using the high sulfur coal.

Aldehydes and Ketones--

The results of these tests are summarized in the data matrix format of Tables 29 and 30, respectively, for boiler unit Nos. 5 and 6. The milligrams of formaldehyde emission per megajoule of heat energy input to the boilers are plotted in Figures 37 and 38, respectively, as a function of nominal RDF heat energy input and nominal steam load of the boilers. Each plotted point on these figures represents the average of three experimental runs.

Figure 37 shows that the formaldehyde emissions generally increase with increases in the RDF heat energy input to the boiler. This is consistent with the fact that as the amount of RDF increases the material containing cellulose fiber, such as wood chips and paper, increases, thus providing the additional formaldehyde emissions. The only exception to this generalization is the data for 100% boiler load on unit No. 5. The data at 100% boiler load and 50% RDF are believed to be unreliable because of the difficulties in operating the boiler at this condition.

TABLE 29. DATA MATRIX OF FORMALDEHYDE EMISSIONS FROM BOILER UNIT NO. 5

```
ALDEHYDES AND KEYTONES FLOW MEASURED AT THE STACK
BOILER NUMBER 5
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

***************************************************************************
*          *                                                              *
*          *                        PERCENT LOAD                          *
* PERCENT  *                                                              *
*          ****************************************************************
* REFUSE   *                    *                    *                    *
*          *        60          *        80          *        100         *
*          *                    *                    *                    *
***************************************************************************
*          * EPA#   (MG/MEGJ)   * EPA#   (MG/MEGJ)   * EPA#   (MG/MEGJ)   *
*          * 04A    2.50E 00    * 05     5.75E-01    * 11     2.57E 00    *
*          * 04B    3.24E 00    * 16     1.28E-01    * 31     1.69E-01    *
*          * 20     2.28E-01    * 17     2.22E-02    * 32     7.21E 00    *
*          * 21     4.24E-01    *                    *                    *
*          * 36     6.92E 00    *                    *                    *
*    0     *                    *                    *                    *
*          * AVE    2.66E 00    * AVE    2.42E-01    * AVE    3.32E 00    *
*          *  SD    2.71E 00    *  SD    2.93E-01    *  SD    3.58E 00    *
*          *  CV    1.02E 00    *  CV    1.21E 00    *  CV    1.08E 00    *
***************************************************************************
*          * EPA#   (MG/MEGJ)   * EPA#   (MG/MEGJ)   * EPA#   (MG/MEGJ)   *
*          * 08     7.42E 00    * 06     3.25E-01    * 07     3.93E 00    *
*          * 09A    3.60E-02    * 12     1.96E-01    * 14     3.20E-02    *
*          * 09B    4.04E 00    * 13     1.31E-01    *                    *
*          * 33     1.02E 00    *                    *                    *
*          *                    *                    *                    *
*   20     *                    *                    *                    *
*          * AVE    3.13E 00    * AVE    2.17E-01    * AVE    1.98E 00    *
*          *  SD    3.33E 00    *  SD    9.87E-02    *  SD    2.75E 00    *
*          *  CV    1.06E 00    *  CV    4.54E-01    *  CV    1.39E 00    *
***************************************************************************
*          * EPA#   (MG/MEGJ)   * EPA#   (MG/MEGJ)   * EPA#   (MG/MEGJ)   *
*          * 01     1.16E 00    * 02     8.57E 00    * 03S    7.80E-02    *
*          * 34     1.55E 01    * 10     3.86E 00    * 18     2.37E-01    *
*          * 35     2.01E 00    * 15     3.84E-01    *                    *
*          *                    *                    *                    *
*          *                    *                    *                    *
*   50     *                    *                    *                    *
*          * AVE    6.22E 00    * AVE    4.27E 00    * AVE    1.57E-01    *
*          *  SD    8.05E 00    *  SD    4.11E 00    *  SD    1.12E-01    *
*          *  CV    1.29E 00    *  CV    9.62E-01    *  CV    7.14E-01    *
***************************************************************************
```

TABLE 30. DATA MATRIX OF FORMALDEHYDE EMISSIONS FROM BOILER UNIT NO 6

```
ALDEHYDES AND KEYTONES FLOW MEASURED AT THE STACK
BOILER NUMBER 6
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

****************************************************************************
*          *                                                               *
*          *                        PERCENT LOAD                           *
* PERCENT  *                                                               *
*          *****************************************************************
* REFUSE   *                    *                    *                     *
*          *         60         *         80         *         100         *
*          *                    *                    *                     *
****************************************************************************
*          *  EPA#   (MG/MEGJ)  *  EPA#   (MG/MEGJ)  *  EPA#   (MG/MEGJ)   *
*          *                    *  24     1.62E 01   *                     *
*          *                    *  29     5.36E-01   *                     *
*          *                    *  30     6.50E-01   *                     *
*          *                    *                    *                     *
*          *                    *                    *                     *
*    0     *                    *                    *                     *
*          *                    *  AVE    5.80E 00   *                     *
*          *                    *   SD    9.02E 00   *                     *
*          *                    *   CV    1.56E 00   *                     *
****************************************************************************
*          *  EPA#   (MG/MEGJ)  *  EPA#   (MG/MEGJ)  *  EPA#   (MG/MEGJ)   *
*          *                    *  25     7.45E-01   *                     *
*          *                    *  26     3.41E-01   *                     *
*          *                    *  27     5.17E-01   *                     *
*          *                    *                    *                     *
*          *                    *                    *                     *
*   20     *                    *                    *                     *
*          *                    *  AVE    6.01E-01   *                     *
*          *                    *   SD    1.25E-01   *                     *
*          *                    *   CV    2.08E-01   *                     *
****************************************************************************
*          *  EPA#   (MG/MEGJ)  *  EPA#   (MG/MEGJ)  *  EPA#   (MG/MEGJ)   *
*          *                    *  22     1.71E 00   *                     *
*          *                    *  23     1.44E 00   *                     *
*          *                    *  28     1.52E 00   *                     *
*          *                    *                    *                     *
*          *                    *                    *                     *
*   50     *                    *                    *                     *
*          *                    *  AVE    1.56E 00   *                     *
*          *                    *   SD    1.42E-01   *                     *
*          *                    *   CV    9.08E-02   *                     *
****************************************************************************
```

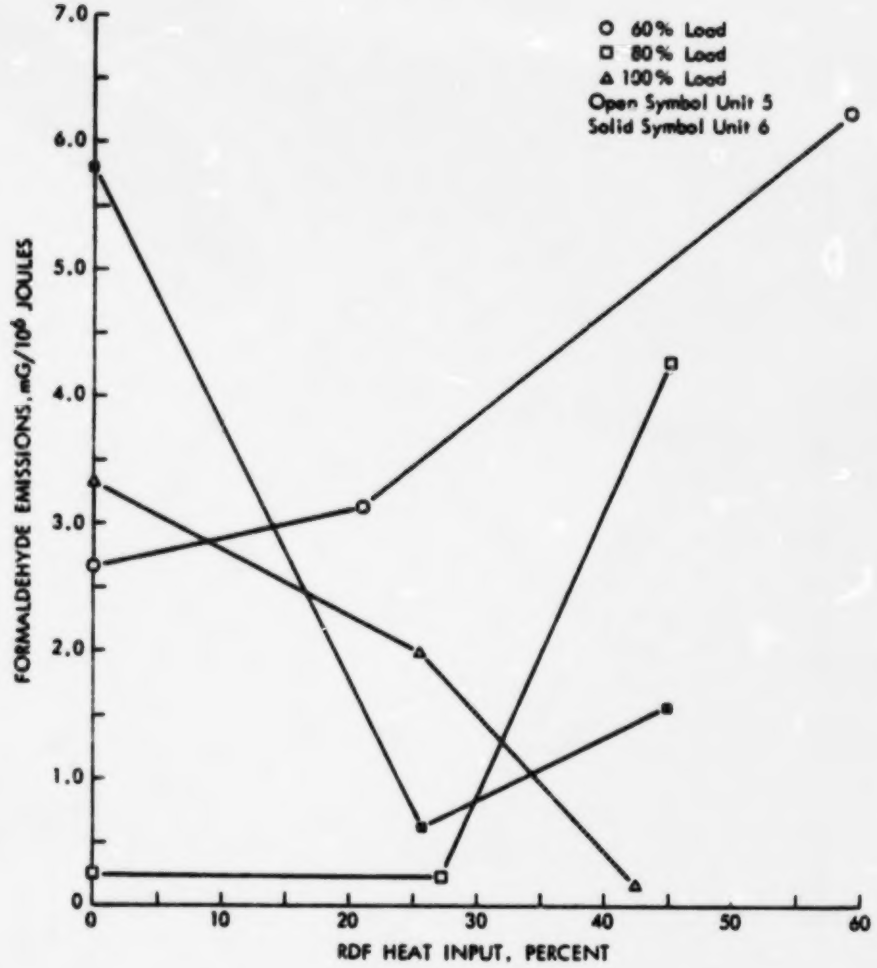


Figure 37. Formaldehyde emissions from boiler unit Nos. 5 and 6 as a function of RDF heat input.

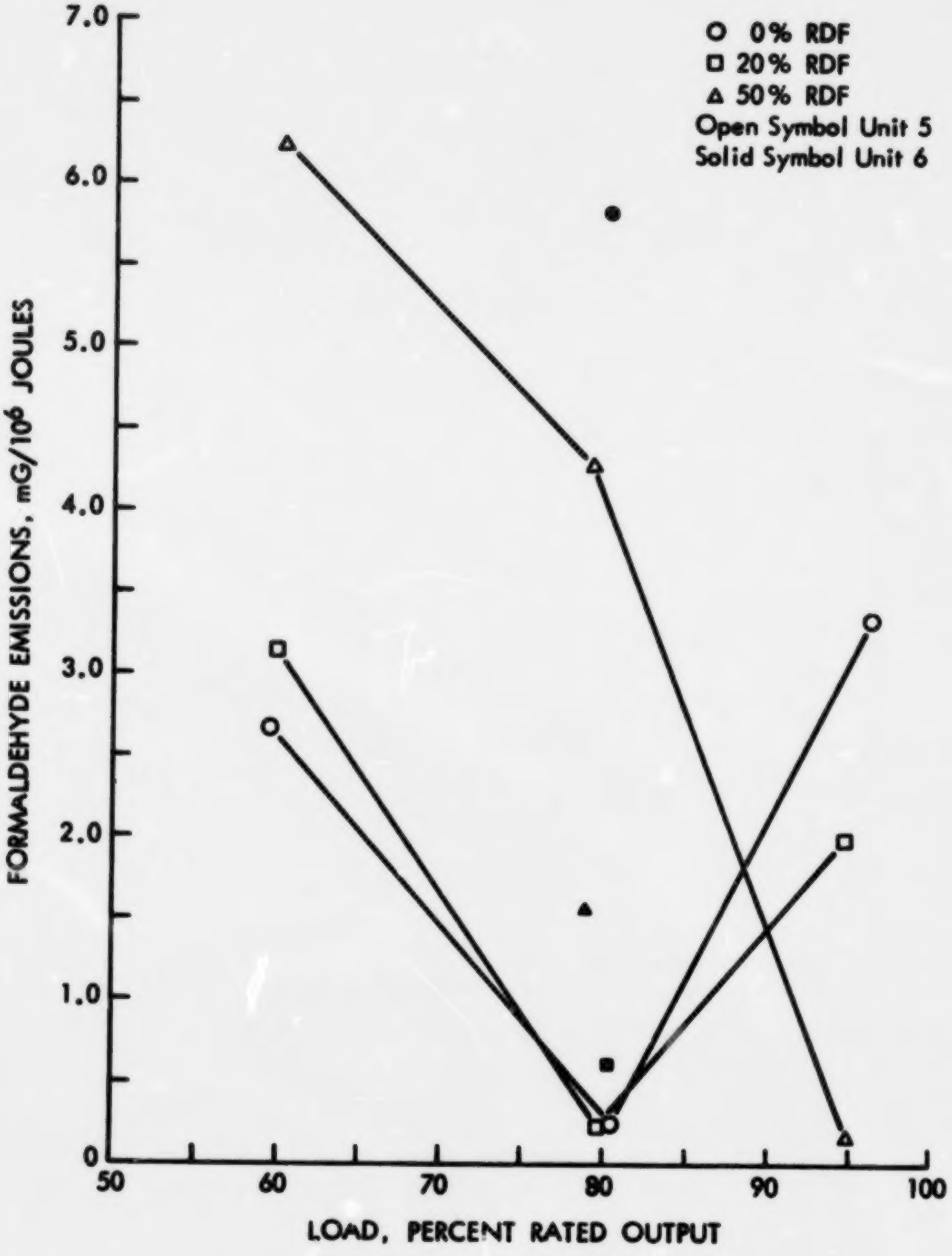


Figure 38. Formaldehyde emissions from boiler unit Nos. 5 and 6 as a function of boiler steam load.

Figure 38 shows that formaldehyde emissions first decrease with load, then increase after passing through a minimum near the 80% boiler load. From other observations and calculations boiler unit No. 5 seems to have its best operation near the 80% boiler load. The boiler operators have the most experience in firing this unit near this load. Thus it is believed that the entire system is operating in a more efficient manner at this level of load which, in turn, helps decrease the formaldehyde emissions. Combustion chamber temperatures were not measured during these experimental runs so correlations of emissions with such temperatures are not obtainable.

Organic Acids, Cyanide, and Phosphate--

Results from the organic acid analysis are not yet available due to difficulties in analysis techniques. Results from the analysis of the chemicals in the organic acid train have yielded both cyanide and phosphate.

The cyanide emissions are tabulated in the data matrix format of Tables 31 and 32, respectively, for boiler unit Nos. 5 and 6. Figures 39 and 40 show the grams of cyanide per megajoule of heat energy input to the boilers plotted, respectively, as a function of percent RDF heat energy input to the boiler and boiler load.

From Figure 39 it is clear that the cyanide emissions increase with increases in RDF for boiler unit No. 5. The trend at 80% load for boiler unit No. 6 is somewhat reversed from that for boiler unit No. 5. Figure 40 indicates a decrease in cyanide emissions with an increase in boiler load.

The phosphate emissions are tabulated in the data matrix format of Tables 33 and 34, respectively, for boiler unit Nos. 5 and 6. Figures 41 and 42 show the grams of phosphate per megajoule of heat energy input to the boilers plotted, respectively, as a function of percent RDF heat energy input to the boiler and boiler load.

From Figure 41 it appears that phosphate emissions generally increase with increases in RDF. However, an exception to the general trend is the 80% load data on boiler unit No. 5. Figure 42 indicates relatively small increases in phosphate emissions as the boiler load increases. Thus, RDF appears to have a larger effect on phosphate emissions than do boiler loads.

Chlorides--

The chloride emissions have been measured by using appropriate analysis of the sulfur dioxide sampling train and the organic acid sampling train. Tables 35 and 36 are tabulations of the results from the sulfur dioxide sampling train for boiler unit Nos. 5 and 6. Tables 37 and 38 are tabulations of the results from the organic acids sampling train for boiler unit Nos. 5 and 6.

TABLE 31. DATA MATRIX OF CYANIDE EMISSIONS FROM BOILER UNIT NO. 5

CYANIDE EMISSIONS, MICROGRAMS PER MEGAJOULE
BOILER NUMBER 5
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

PERCENT REFUSE	PERCENT LOAD					
	60		80		100	
0	EPA#	(UG/MEGJ)	EPA#	(UG/MEGJ)	EPA#	(UG/MEGJ)
	04A	2.05E 02	05	1.18E 02	11	1.01E 02
	04B	2.09E 02	16	3.65E 02	31	3.09E 01
	20	1.39E 02	17	1.68E 02	32	1.50E 02
	21	1.55E 02				
	36	1.82E 01				
	AVE	1.53E 02	AVE	2.17E 02	AVE	9.42E 01
	SD	8.06E 01	SD	1.31E 02	SD	6.00E 01
	CV	5.26E-01	CV	6.02E-01	CV	6.37E-01
20	EPA#	(UG/MEGJ)	EPA#	(UG/MEGJ)	EPA#	(UG/MEGJ)
	08	8.68E 01	06	8.29E 01	07	1.90E 02
	09A	2.15E 02	12	2.07E 02	14	1.08E 02
	09B	1.60E 02	13	2.17E 02		
	33	2.82E 02				
	AVE	1.86E 02	AVE	1.69E 02	AVE	1.49E 02
	SD	8.29E 01	SD	7.47E 01	SD	5.80E 01
	CV	4.46E-01	CV	4.42E-01	CV	3.90E-01
50	EPA#	(UG/MEGJ)	EPA#	(UG/MEGJ)	EPA#	(UG/MEGJ)
	01	1.88E 02	02	2.12E 02	03S	1.77E 02
	34	3.22E 02	10	9.64E 01	18	1.67E 02
	35	4.26E 02	15	2.57E 02		
	AVE	3.12E 02	AVE	1.89E 02	AVE	1.72E 02
	SD	1.20E 02	SD	8.29E 01	SD	6.58E 00
	CV	3.83E-01	CV	4.40E-01	CV	3.83E-02

TABLE 32. DATA MATRIX OF CYANIDE EMISSIONS FROM BOILER UNIT NO. 6

CYANIDE EMISSIONS, MICROGRAMS PER MEGAJOULE
BOILER NUMBER 6
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

PERCENT REFUSE	PERCENT LOAD		
	60	80	100
0	EPA# (UG/MEGJ)	EPA# (UG/MEGJ) 24 1.71E 01 29 1.18E 02 30 1.53E 02 AVE 9.61E 01 SD 7.06E 01 CV 7.35E-01	EPA# (UG/MEGJ)
20	EPA# (UG/MEGJ)	EPA# (UG/MEGJ) 25 2.62E 02 26 1.92E 02 27 1.95E 02 AVE 2.16E 02 SD 3.93E 01 CV 1.82E-01	EPA# (UG/MEGJ)
50	EPA# (UG/MEGJ)	EPA# (UG/MEGJ) 22 1.15E 02 23 2.21E 02 28 1.44E 02 AVE 1.60E 02 SD 5.46E 01 CV 3.42E-01	EPA# (UG/MEGJ)

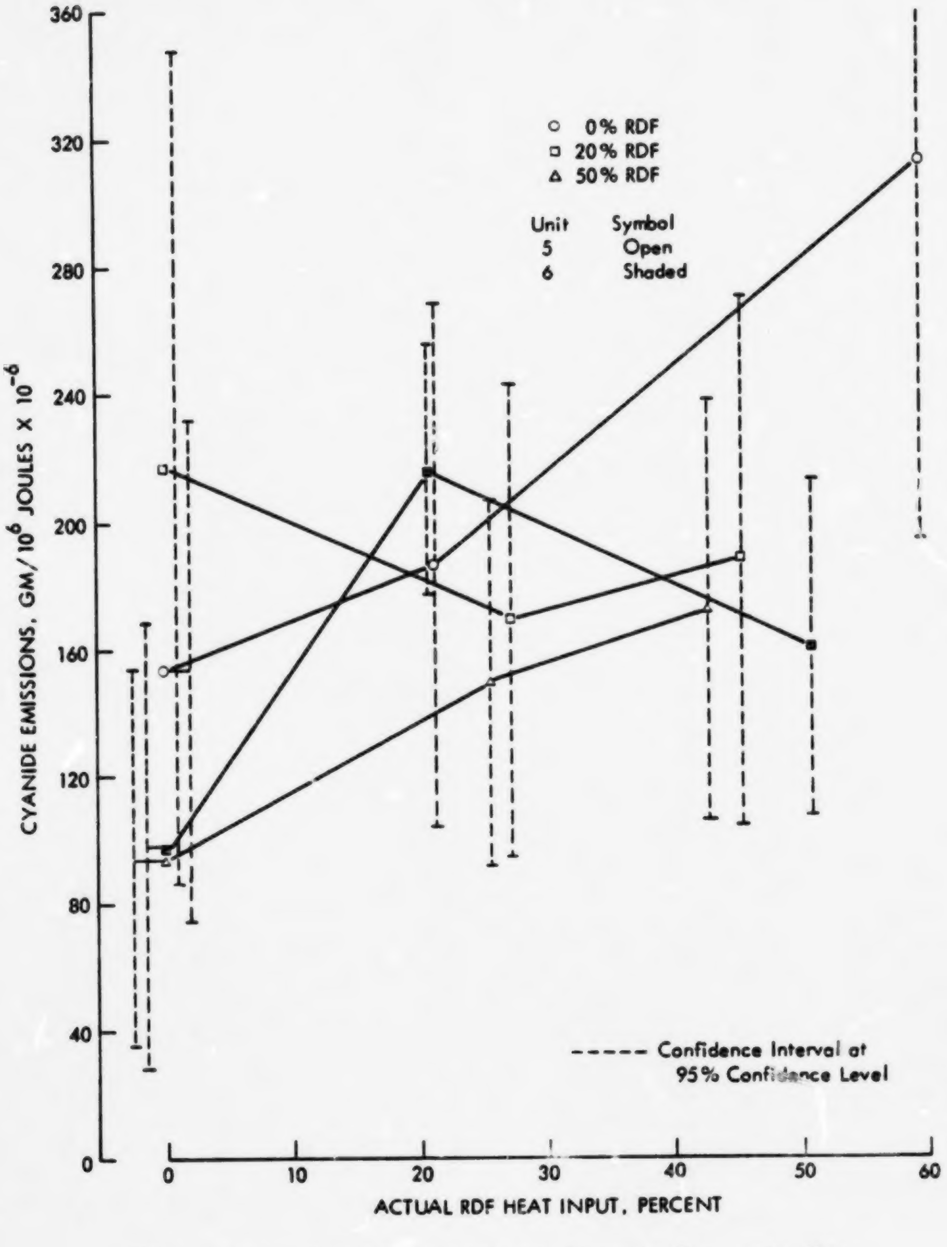


Figure 39. Cyanide emissions from boiler unit Nos. 5 and 6 as a function of RDF heat input.

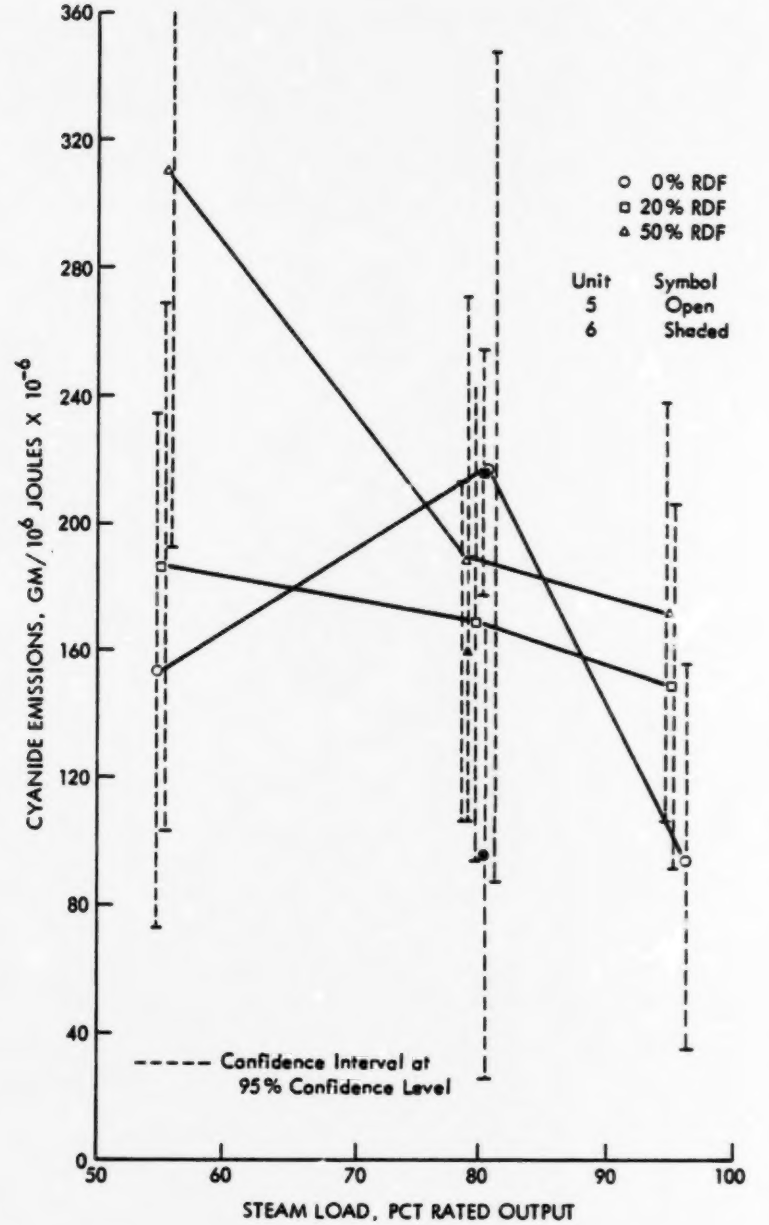


Figure 40. Cyanide emissions from boiler unit Nos. 5 and 6 as a function of boiler steam load.

TABLE 33. DATA MATRIX OF PHOSPHATE EMISSIONS FROM BOILER UNIT NO. 5

```
PO4 FLOW MEASURED AT THE STACK
BOILER NUMBER 5
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

**********************************************************************
*          *                                                         *
*          *                      PERCENT LOAD                       *
* PERCENT  *                                                         *
*          ***********************************************************
* REFUSE   *                  *                  *                   *
*          *        60        *        80        *        100        *
*          *                  *                  *                   *
**********************************************************************
*          * EPA#  (MG/MEGJ)  * EPA#  (MG/MEGJ)  * EPA#  (MG/MEGJ)   *
*          * 04A   8.20E-02   * 05    1.06E-01   * 11    3.00E-02    *
*          * 04B   8.40E-02   * 16    0.00E-01   * 31    1.90E-01    *
*          * 20    0.00E-01   * 17    1.99E 00   * 32    1.10E-01    *
*          * 21    0.00E-01   *                  *                   *
*          * 36    0.00E-01   *                  *                   *
*    0     *                  *                  *                   *
*          * AVE   3.32E-02   * AVE   6.97E-01   * AVE   1.10E-01    *
*          *  SD   4.55E-02   *  SD   1.12E 00   *  SD   8.00E-02    *
*          *  CV   1.37E 00   *  CV   1.60E 00   *  CV   7.27E-01    *
**********************************************************************
*          * EPA#  (MG/MEGJ)  * EPA#  (MG/MEGJ)  * EPA#  (MG/MEGJ)   *
*          * 08    2.17E-01   * 06    2.49E-01   * 07    1.52E-01    *
*          * 09A   1.72E-01   * 12    0.00E-01   * 14    0.00E-01    *
*          * 09B   4.90E-02   * 13    0.00E-01   * 19    0.00E-01    *
*          * 33    1.90E-01   *                  *                   *
*          *                  *                  *                   *
*   20     *                  *                  *                   *
*          * AVE   1.57E-01   * AVE   8.30E-02   * AVE   5.07E-02    *
*          *  SD   7.43E-02   *  SD   1.44E-01   *  SD   8.78E-02    *
*          *  CV   4.73E-01   *  CV   1.73E 00   *  CV   1.73E 00    *
**********************************************************************
*          * EPA#  (MG/MEGJ)  * EPA#  (MG/MEGJ)  * EPA#  (MG/MEGJ)   *
*          * 01    1.40E 00   * 02    0.00E-01   * 03S   1.90E-01    *
*          * 34    0.00E-01   * 10    3.90E-02   * 18    1.77E-01    *
*          * 35    0.00E-01   * 15    0.00E-01   *                   *
*          *                  *                  *                   *
*          *                  *                  *                   *
*   50     *                  *                  *                   *
*          * AVE   4.66E-01   * AVE   1.30E-02   * AVE   1.83E-01    *
*          *  SD   8.07E-01   *  SD   2.25E-02   *  SD   9.19E-03    *
*          *  CV   1.73E 00   *  CV   1.73E 00   *  CV   5.01E-02    *
**********************************************************************
```

TABLE 34. DATA MATRIX OF PHOSPHATE EMISSIONS FROM BOILER UNIT NO. 6

```
PO4 FLOW MEASURED AT THE STACK
BOILER NUMBER 6
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

**********************************************************************
*          *                                                         *
*          *                      PERCENT LOAD                       *
* PERCENT  *                                                         *
*          ***********************************************************
* REFUSE   *                  *                  *                   *
*          *        60        *        80        *        100        *
*          *                  *                  *                   *
**********************************************************************
*          *  EPA#  (MG/MEGJ) * EPA#  (MG/MEGJ)  *  EPA#  (MG/MEGJ)  *
*          *                  * 24    0.00E-01   *                   *
*          *                  * 29    0.00E-01   *                   *
*          *                  * 30    0.00E-01   *                   *
*          *                  *                  *                   *
*          *                  *                  *                   *
*    0     *                  *                  *                   *
*          *                  * AVE   0.00E-01   *                   *
*          *                  *  SD   0.00E-01   *                   *
*          *                  *  CV   1.00E 20   *                   *
**********************************************************************
*          *  EPA#  (MG/MEGJ) * EPA#  (MG/MEGJ)  *  EPA#  (MG/MEGJ)  *
*          *                  * 25    0.00E-01   *                   *
*          *                  * 26    0.00E-01   *                   *
*          *                  * 27    0.00E-01   *                   *
*          *                  *                  *                   *
*          *                  *                  *                   *
*   20     *                  *                  *                   *
*          *                  * AVE   0.00E-01   *                   *
*          *                  *  SD   0.00E-01   *                   *
*          *                  *  CV   1.00E 20   *                   *
**********************************************************************
*          *  EPA#  (MG/MEGJ) * EPA#  (MG/MEGJ)  *  EPA#  (MG/MEGJ)  *
*          *                  * 22    7.95E-01   *                   *
*          *                  * 23    1.23E 00   *                   *
*          *                  * 28    0.00E-01   *                   *
*          *                  *                  *                   *
*          *                  *                  *                   *
*   50     *                  *                  *                   *
*          *                  * AVE   6.74E-01   *                   *
*          *                  *  SD   6.22E-01   *                   *
*          *                  *  CV   9.23E-01   *                   *
**********************************************************************
```

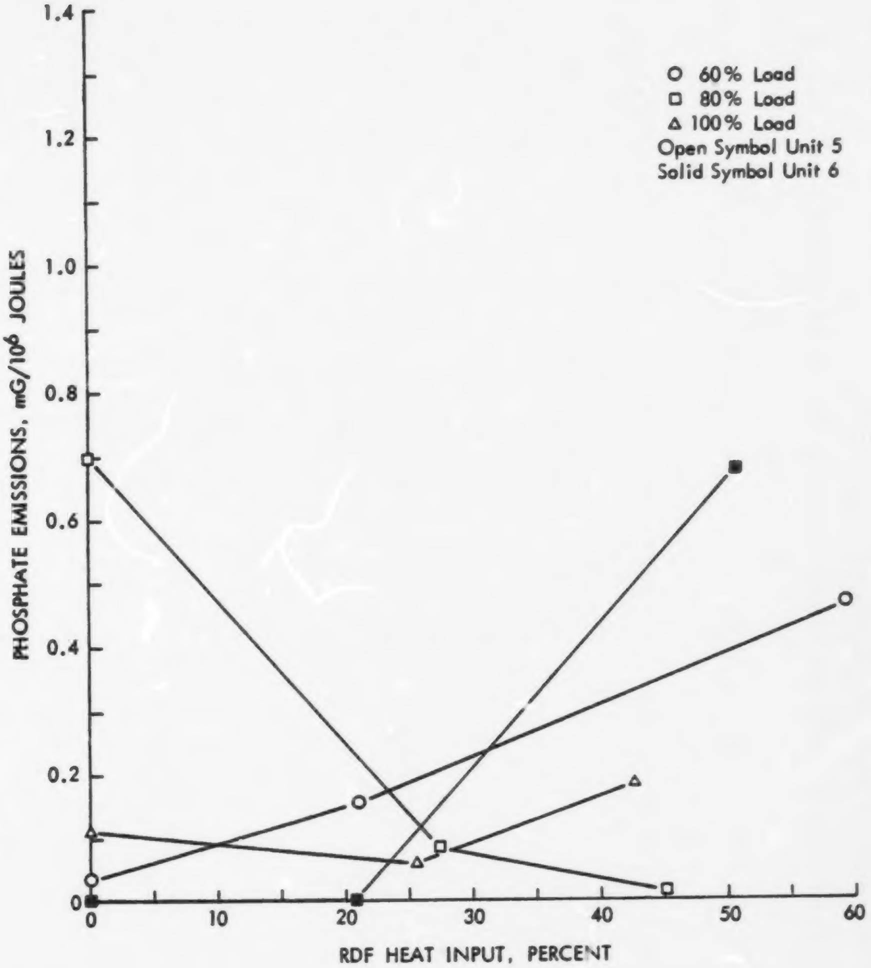


Figure 41. Phosphate emissions from boiler unit Nos. 5 and 6 as a function of RDF heat input.

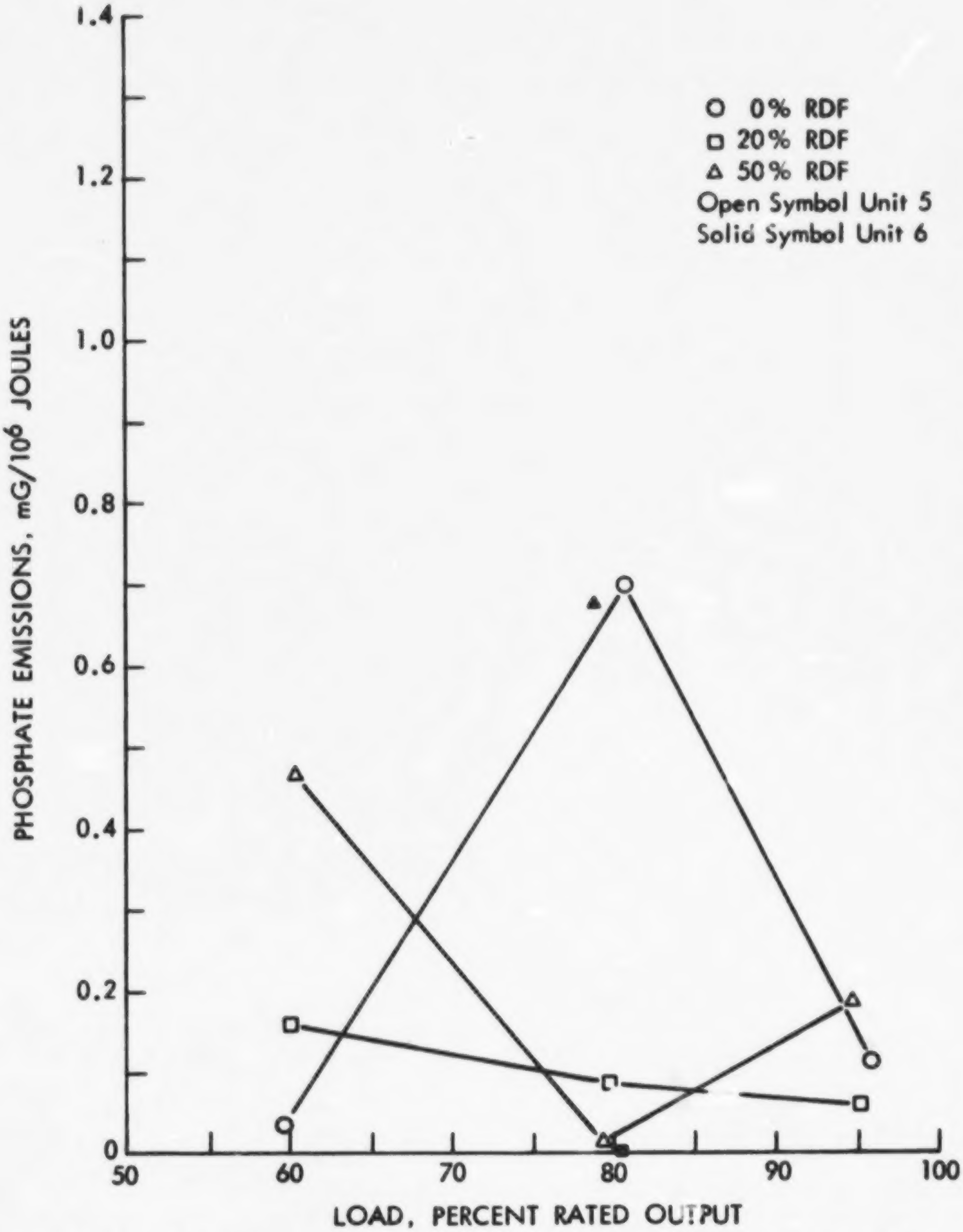


Figure 42. Phosphate emissions from boiler unit Nos. 5 and 6 as a function of boiler steam load.

TABLE 35. DATA MATRIX OF CHLORIDE EMISSIONS FROM BOILER UNIT NO. 5 AS DETERMINED BY THE SO_x SAMPLING TRAIN

```
CHLORINE FLOW USING SOX METHOD MEASURED AT THE STACK
BOILER NUMBER 5
PERCENT REFUSE AND LOAD ARE NUMINAL VALUES

*************************************************************************************
*              *                                                                    *
*              *                            PERCENT LOAD                            *
* PERCENT      *                                                                    *
*              **********************************************************************
* REFUSE       *                      *                      *                      *
*              *          60          *          80          *         100          *
*              *                      *                      *                      *
*************************************************************************************
*              *  EPA#   (MG/MEGJ)    *  EPA#   (MG/MEGJ)    *  EPA#   (MG/MEGJ)    *
*              *  04A    4.00E 01     *  05     1.10E 01     *  11     7.00E 00     *
*              *  04B    1.80E 01     *  16     1.10E 01     *                      *
*              *  20     1.50E 01     *  17     1.60E 01     *                      *
*              *  36     1.60E 01     *                      *                      *
*              *                      *                      *                      *
*      0       *                      *                      *                      *
*              *  AVE    2.23E 01     *  AVE    1.27E 01     *  AVE    7.00E 00     *
*              *   SD    1.19E 01     *   SD    2.89E 00     *   SD    0.00E-01     *
*              *   CV    5.35E-01     *   CV    2.28E-01     *   CV    0.00E-01     *
*************************************************************************************
*              *  EPA#   (MG/MEGJ)    *  EPA#   (MG/MEGJ)    *  EPA#   (MG/MEGJ)    *
*              *  08     4.00E 01     *  06     5.00E 01     *  07     3.90E 01     *
*              *  09A    7.00E 01     *  12     7.00E 01     *  14     6.40E 01     *
*              *  09B    7.50E 01     *  13     7.50E 01     *  19     8.30E 01     *
*              *  33     4.70E 01     *                      *                      *
*              *                      *                      *                      *
*     20       *                      *                      *                      *
*              *  AVE    5.80E 01     *  AVE    6.83E 01     *  AVE    6.20E 01     *
*              *   SD    1.71E 01     *   SD    7.64E 00     *   SD    2.21E 01     *
*              *   CV    2.95E-01     *   CV    1.12E-01     *   CV    3.56E-01     *
*************************************************************************************
*              *  EPA#   (MG/MEGJ)    *  EPA#   (MG/MEGJ)    *  EPA#   (MG/MEGJ)    *
*              *  01     3.90E 01     *  02     5.10E 01     *  03S    1.16E 02     *
*              *  34     1.17E 02     *  10     1.37E 02     *  18     8.60E 01     *
*              *  35     1.44E 02     *  15     1.03E 02     *                      *
*              *                      *                      *                      *
*              *                      *                      *                      *
*     50       *                      *                      *                      *
*              *  AVE    1.00E 02     *  AVE    9.70E 01     *  AVE    1.01E 02     *
*              *   SD    5.45E 01     *   SD    4.33E 01     *   SD    2.12E 01     *
*              *   CV    5.45E-01     *   CV    4.47E-01     *   CV    2.10E-01     *
*************************************************************************************
```

TABLE 36. DATA MATRIX OF CHLORIDE EMISSIONS FROM BOILER UNIT NO. 6 AS DETERMINED BY THE SO_x SAMPLING TRAIN

CHLORINE FLOW USING SOX METHOD MEASURED AT THE STACK
BOILER NUMBER 6
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

PERCENT REFUSE	PERCENT LOAD		
	60	80	100
0	EPA# (MG/MEGJ)	EPA# (MG/MEGJ) 24 1.00E 01 29 5.00E 00 30 4.00E 00 AVE 6.33E 00 SD 3.21E 00 CV 5.08E-01	EPA# (MG/MEGJ)
20	EPA# (MG/MEGJ)	EPA# (MG/MEGJ) 25 4.70E 01 27 4.00E 01 AVE 4.35E 01 SD 4.95E 00 CV 1.14E-01	EPA# (MG/MEGJ)
50	EPA# (MG/MEGJ)	EPA# (MG/MEGJ) 23 1.11E 02 28 6.40E 01 AVE 8.75E 01 SD 3.32E 01 CV 3.80E-01	EPA# (MG/MEGJ)

TABLE 37. DATA MATRIX OF CHLORIDE EMISSIONS FROM BOILER UNIT NO. 5 AS DETERMINED BY THE ORGANIC ACIDS TRAIN

CHLORINE FLOW MEASURED AT THE STACK
USING CHLORIDES AND ORGANIC ACIDS METHOD
BOILER NUMBER 5
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

PERCENT REFUSE	PERCENT LOAD					
	60		80		100	
0	EPA#	(MG/MEGJ)	EPA#	(MG/MEGJ)	EPA#	(MG/MEGJ)
	04A	7.78E 00	05	1.83E 01	11	3.75E 01
	04B	1.47E 01	16	6.91E 00	31	7.50E 00
	20	2.56E 01	17	5.12E 00	32	1.15E 01
	21	2.41E 01				
	36	2.24E 01				
	AVE	1.89E 01	AVE	1.01E 01	AVE	1.88E 01
	SD	7.50E 00	SD	7.16E 00	SD	1.63E 01
	CV	3.97E-01	CV	7.08E-01	CV	8.66E-01
20	EPA#	(MG/MEGJ)	EPA#	(MG/MEGJ)	EPA#	(MG/MEGJ)
	08	8.16E 01	06	1.21E 02	07	6.96E 01
	09A	7.26E 01	12	1.18E 02	14	9.51E 01
	09B	4.88E 01	13	1.17E 02		
	33	7.32E 01				
	AVE	6.91E 01	AVE	1.18E 02	AVE	8.23E 01
	SD	1.41E 01	SD	2.22E 00	SD	1.80E 01
	CV	2.04E-01	CV	1.87E-02	CV	2.19E-01
50	EPA#	(MG/MEGJ)	EPA#	(MG/MEGJ)	EPA#	(MG/MEGJ)
	01	1.16E 02	02	7.70E 01	03S	5.39E 01
	34	5.93E 01	10	9.33E 01	18	1.06E 02
	35	1.51E 02	15	9.36E 01		
	AVE	1.09E 02	AVE	8.80E 01	AVE	7.98E 01
	SD	4.62E 01	SD	9.54E 00	SD	3.66E 01
	CV	4.25E-01	CV	1.08E-01	CV	4.59E-01

TABLE 38. DATA MATRIX OF CHLORIDE EMISSIONS FROM BOILER UNIT NO. 6 AS DETERMINED BY THE ORGANIC ACIDS TRAIN

CHLORINE FLOW MEASURED AT THE STACK
USING CHLORIDES AND ORGANIC ACIDS METHOD
BOILER NUMBER 6
PERCENT REFUSE AND LOAD ARE NOMINAL VALUES

PERCENT REFUSE	PERCENT LOAD		
	60	80	100
0	EPA# (MG/MEGJ)	EPA# (MG/MEGJ) 24 2.32E 01 29 8.00E 00 30 1.05E 01 AVE 1.39E 01 SD 8.15E 00 CV 5.86E-01	EPA# (MG/MEGJ)
20	EPA# (MG/MEGJ)	EPA# (MG/MEGJ) 25 5.60E 01 26 5.59E 01 27 4.71E 01 AVE 5.30E 01 SD 5.12E 00 CV 9.67E-02	EPA# (MG/MEGJ)
50	EPA# (MG/MEGJ)	EPA# (MG/MEGJ) 22 1.35E 02 23 1.85E 02 28 7.00E 01 AVE 1.30E 02 SD 5.76E 01 CV 4.43E-01	EPA# (MG/MEGJ)

Figures 43 and 44 give the chloride emissions from the sulfur dioxide samplin train as a function of nominal RDF and nominal load, respectively. Figures 45 and 46 give the chloride emissions from the organic acids sampling train as a function of nominal RDF and nominal load respectively.

Figures 43 and 45 show the chloride emissions to increase significantly with increases in RDF heat energy input to the boiler. Figures 44 and 46 show relatively small changes in chloride emissions with load. The chloride analysis from the two different sampling trains are in good agreement concerning variation with RDF and variation with load. Thus, the chloride emissions appear to be mainly related to the RDF input to the boilers.

Mercury, Arsenic, Antimony, and Beryllium Under Effluent Flow Rates Under Chlorides--

The results from the mercury sampling trains are not yet ready for presentation. However, analysis of the mercury train impinger chemicals for the elements has been accomplished. This data is tabulated in Appendix L in the data matrix format and alphabetical by element. The tabulation includes analysis of impingers containing iodine monochloride (ICl), nitric acid (HNO_3), and potassium hydroxide (KOH).

Appendices M, N, and O are tabulations of the ICl analysis, the HNO_3 analysis, and the KOH analysis, respectively, by EPA test sequence. These appendices predict the effluents of the elements from the stack based on the flow rate measurements and the chemical element analysis. The predicted effluents of chemical elements from this analysis may be different from the previous predictions from the particulate filters and particulate water because of the sampling rates and impinger chemicals used in the various sampling trains.

Hydrocarbons--

No significant hydrocarbon emissions ($>$0.25 ppm) in the C_1 to C_5 range have been found in the stack emissions.

Organics--

Results of sampling for organics including polychlorinated biphenyls (PCB) and polynuclear aromatics are summarized below.

PCBs--The usual procedure for the recovery and determination of PCB from various sample materials is being followed. This procedure involves extraction with a suitable solvent, cleanup of the extract using column chromatography and detection, and determination using electron capture gas chromatography (ECGC). With this procedure, no PCBs could be detected in the coal samples, in vapor samples collected from the stack on macroreticular resin, in particulates from the dust collector or in particulates from the stack.

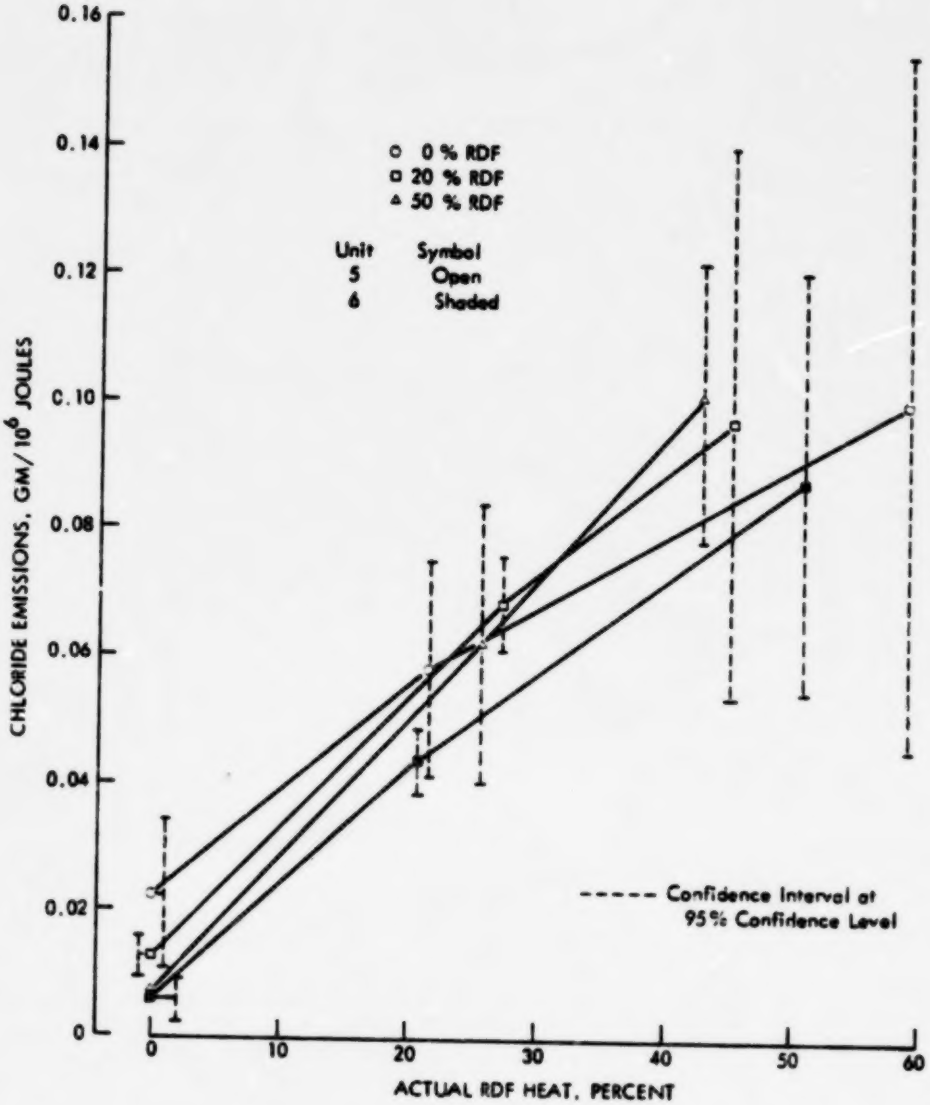


Figure 43. Chloride emissions from boiler unit Nos. 5 and 6 as a function of RDF heat input as determined by the SO_x train.

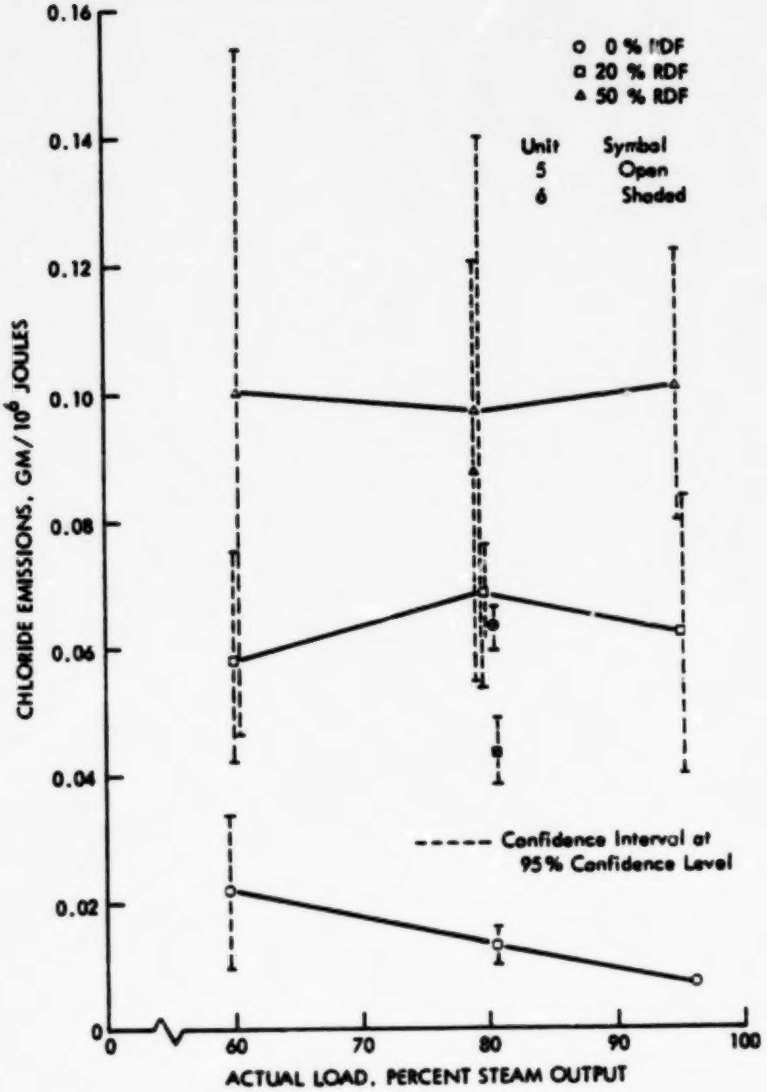


Figure 44. Chloride emissions from boiler unit Nos. 5 and 6 as a function of boiler steam load as determined by the SO_x train.

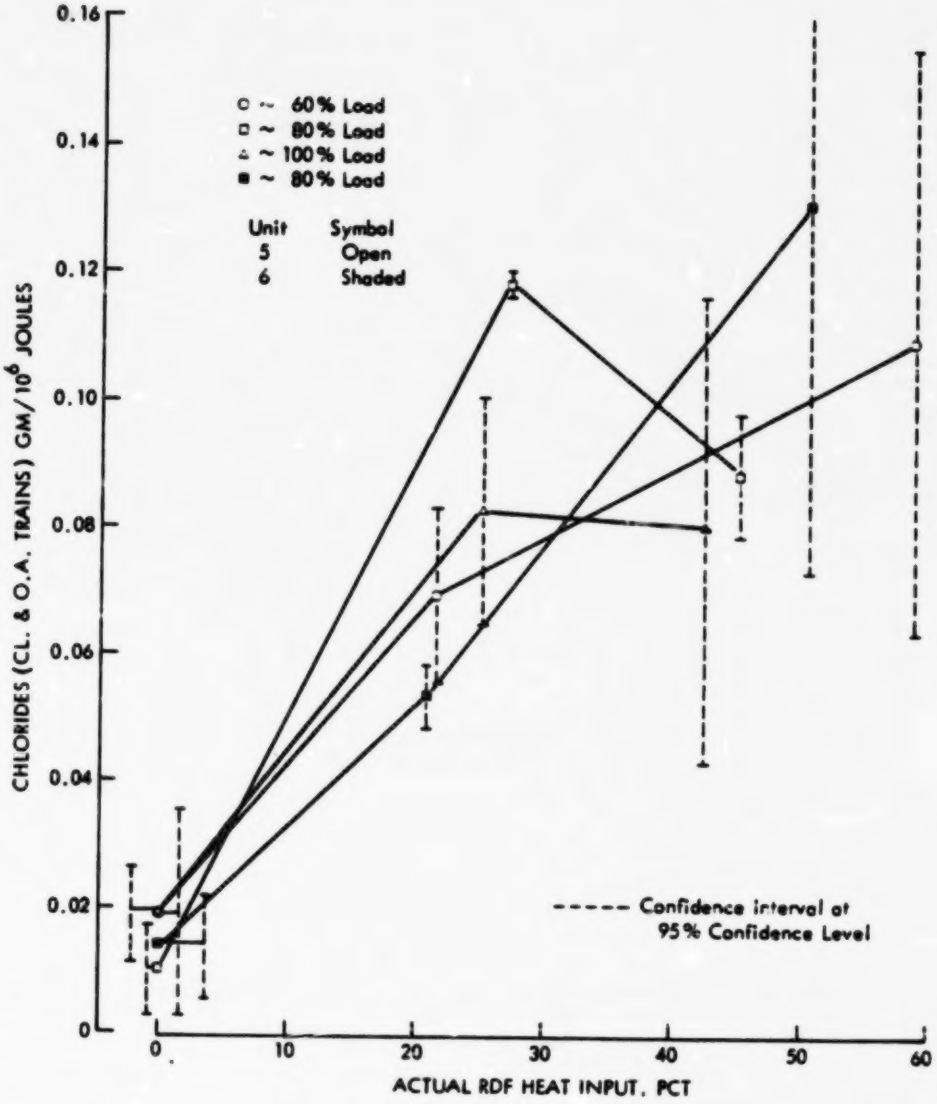


Figure 45. Chloride emissions from boiler unit Nos. 5 and 6 as a function of RDF heat input as determined by the organic acids train.

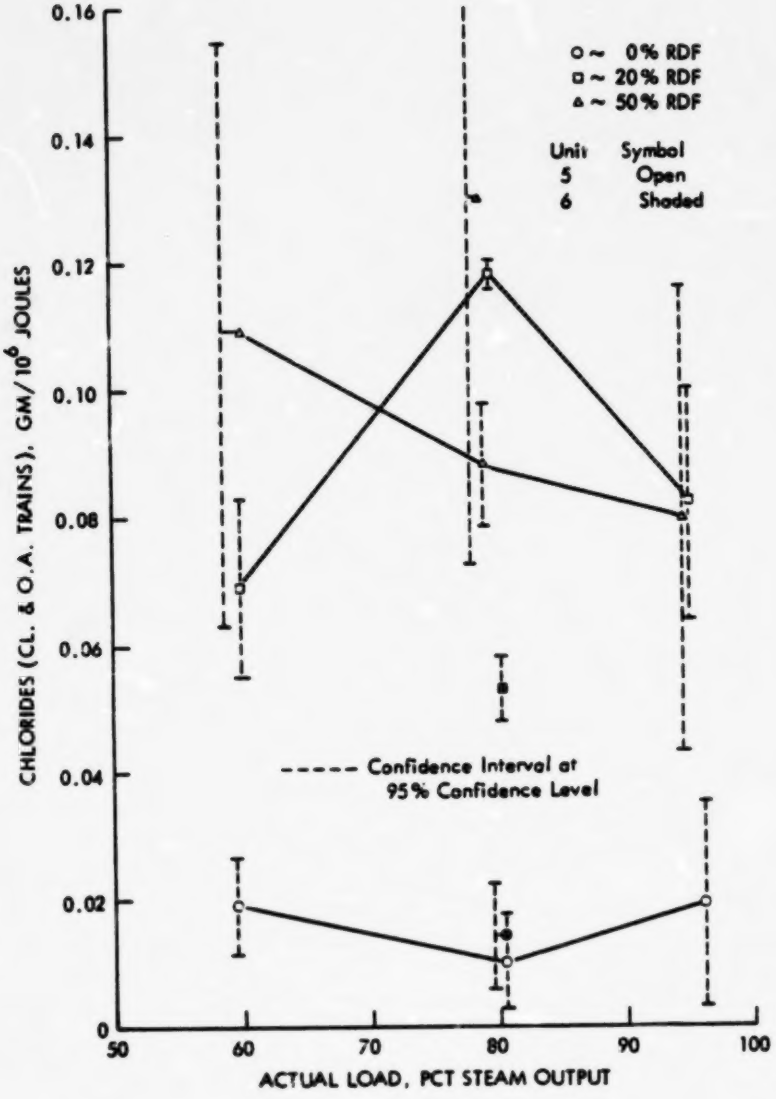


Figure 46. Chloride emissions from boiler unit Nos. 5 and 6 as a function of boiler steam load as determined by the organic acids train.

The detection limit for this method is approximately 10 ppb. The limit of the method can be increased to approximately 10 ppt by the perchlorination of the PCBs. Negative results were also obtained for the various samples using this perchlorination procedure. A recovery study was run on a dust collector sample deliberately spiked with PCBs at the 1 ppb level. A 95% recovery was obtained from the spiked sample.

In the case of the solid waste fuel, the initial experiment on perchlorination of the extract obtained by Soxhlet extracting a quantity of ground processed refuse was positive. That is, a large peak was obtained for decachlorobiphenyl. This peak could be caused by degradation of some component of the refuse by the $SbCl_5$, used as the perchlorinating reagent to give biphenyl which in turn is chlorinated to the decachlorobiphenyl. This possibility was investigated by following the standard, but longer procedure for isolation and determination of PCBs. This involves extraction cleanup, and separation using the procedure of Armos and Burke,[11] The retention times of the major peaks of the extracts from the refuse matched the major peaks of the arachlox 1254 and 1248 standards. The approximated concentration of PCBs in the solid waste was 0.5 ppm.

Polynuclear aromatics (PNA)--

Gas phase results--Twenty-eight gas phase samples ranging in volume from 40 to 1,500 liters were taken from the power plant stack and subjected to separation, isolation, detection, and quantitation schemes. From 0.1 to 43 µm/liters were measured with no correlation to firing conditions or the amount of solid waste being burned. Quantified compounds found in the stack emissions are given in Table 39. Additional identified constituents were phenol, o-cresol tolueme, diphenylamine, di-(2 -ethylhexyl)-phthalate, and triphenylphosphate. Of this group the common flame retardent, triphenylphosphate, is the only constituent of immediate interest and could be caused by either treated coal or a portion of the refuse. Ambient air samples were also collected and analyzed. The amount of organic material found was shown to be a function of vehicular traffic rather than stack emissions.

Particulate results--Most of the particulate samples were collected from inside the stack at the power plant. Twenty-four samples ranging in amounts from 0.03 to 110 g were collected. Complete analysis of these samples showed that the organic content was highly variable and complex. The dominant constituents were saturated hydrocarbons with lesser amounts of unknown polar materials. The upper limit for PNA content was 6.8 ng/g. This designation of total PNA is based solely on the classification scheme and relative gas chromatography (GC) retention times. Insufficient material was available for confirmation using the available gas chromatography/mass spectrometry (GC/MS) instrumentation. An upper limit of 0.3 ng/g for perylene has been established using the identification scheme explained above.

TABLE 39. ORGANIC COMPOUNDS IN STACK EMISSIONS

Compound	Stack Gases ($\mu g/1,000\ m^3$)	Particulates (ng/g)
Naphthalene	BDL[a]	BDL
Acenaphthalene	BDL	BDL
Fluorene	36.5	BDL
Anthracene	BDL	BDL
Fluoranthene	119	BDL
Pyrene	36.5	BDL
Benzofluorenes (1,2 and 2,3)	54.7	BDL
1,2 Benzanthracene	BDL	BDL
a and e Benzpyrenes and Perylene	72.9	0.42
20 Methylcholanthrene	BDL	BDL
Dibenzanthracenes (1,2-3,4 and A, H)	BDL	BDL
Dibenzanthracene (2,3-6,7)	BDL	BDL
Coronene and 3,4-9,10 Dibenzopyrene	BDL	BDL
Aliphatic hydrocarbons	31,700	340
Detection Limits	35 $\mu g/1,000\ m^3$	0.35 ng/g

[a] BDL = Below Detection Limit.

Impinger water results--Sixteen samples of impinger water collected in a standard EPA Method 5 sampling train have been assayed. The organic content of these waters are in the mg/liter range and specific contaminants are xylene, tetramethylbenzene, diethylphthalate, dimethylphenol, phthalic anhydride, t-butylphenol, t-butylcresol, and di-t-butylethylphenol. A series of silicones were identified in three water samples but these were apparently artifacts caused by contamination from one of several connectors used in the sampling train. Consistency in the contamination amounts has not yet been observed and no definitive significance has been placed on these impinger water results.

Miscellaneous--

Elemental sulfur in coal and particulates--Elemental sulfur was determined by combining electron capture (EC) detection with cyclohexane extractions of coal and particulates. The sensitivity for sulfur permitted its determination in the samples at subparts per billion levels. The extraction procedures allowed for a minimum of cleanup prior to the gas chromatography (GC) which is both rapid and selective.

Particulate samples were collected from the 3-in. sampling ports located approximately halfway up the stack of the unit No. 5 boiler. Three types of samples were collected. Particulates No. 1 were from the accumulation in the ports. Particulates No. 2 were collected by drawing the vapor from inside the stack through a glass tube containing a glass wool plug. Particulates No. 3 represented that portion which settled onto horizontal trays placed inside the stack.

Ten grams of particulates were Soxhlet extracted for 24 hr in 25 x 85 mm glass thimbles using approximately 50 ml of cyclohexane. The cyclohexane was transferred to volumetric flasks and diluted to 50 ml with cyclohexane. Five micoliters aliquots of this solution were gas chromatographed without further cleanup.

Elemental sulfur content of particulates--

Sample	No. Samples	Range (μg/g)	Average (μg/g)
No. 1	3	150-250	198
No. 2	2	65-87	76
No. 3	10	4-15	9

The variation in the results obtained for the three types of sampling suggests some correlation with particulate size. Because of the large amount of sample required (10 g) a determination as a fraction of size has not been accomplished.

Four samples of Iowa coal, one of Wyoming coal, and one of Illinois coal were analyzed for elemental sulfur. The coal was crushed and 1-g samples which had passed a 60-mesh sieve were Soxhlet extracted for 24 hr. Large 35 x 90-mm glass thimbles were used to prevent plugging of the Soxhlet device by the fines from the coal samples. The 90 ml of cyclohexane used for the extraction was then quantitatively transferred to volumetric flasks and diluted to 100 ml. Five-micoliters aliquots of this cyclohexane solution was gas chromatographed directly without further cleanup.

Elemental sulfur content of coals--

Coal Source	μg/g
Iowa Sample No. 1	1,000
Iowa Sample No. 2	2,080
Iowa Sample No. 3	280
Iowa Sample No. 4	205
Wyoming	160
Illinois	398

Comparison of low and high temperature ashing of solid waste from the Ames solid waste recycling plant--

Sample preparation--A solid waste sample was dried overnight at 105°C to provide partial sterilization and then passed through a Wiley mill with a 2-mm screen. The resulting material was a medium grey colored, very lightweight mixture of fibers. Other small, lighter colored particles were fairly evenly distributed throughout.

Several grams were oxidized using the International Plasma Corporation plasma ashing apparatus. Contrary to original expectations, this was a lengthy process which required about 10 days to obtain constant weight. The ash was found to be 15.92% of the dried, milled starting material. Small pieces of glass and stone were present in the ash.

An additional 10 g of the sample were ashed at 800°C for 1 hr. The ash was found to be 11.23% of the starting material. Small pieces of glass and other noncombustibles were also apparent in this ash.

X-ray fluorescence analysis--The two ash samples were analyzed using an energy dispersive X-ray fluorescence analyzer. A molybdenum target X-ray tube was used to 12 kV to excite low atomic weight elements and at

30 kV to excite heavier elements. The ashed samples were placed in a chemplex holder with a thin mylar film supporting the ash. The samples were not compressed. Equal volumes of the two samples were used. The major difference in the 12 kV spectra of the two samples was the absence of chlorine in the sample ashed at 800°C. At 30 kV the main difference in the two spectra was the absence of bromine in the sample ashed at 800°C. Spectral interferences from Br and Pb interfere with the detection of Ga, As, and Se. The ratio of incoherent to coherent scattered Mo radiation was found to be higher in the plasma ashed sample, which indicates a higher concentration of low atomic weight elements (such as H, C, N, O). This observation is in agreement with the larger amount of ash in the plasma ashed sample. Even though the ashing had been continued for 1[illegible] days to reach constant weight, it appears that some organic material remained unoxidized.

Numerical comparisons--The integrated background corrected counts for many of the spectral features are presented in Table 40. The ratios of counts for the two ash samples are also given. Due to the variable nature of the sample, the ratios differ considerably from sample to sample. However, ratios significantly less than 1.00 probably indicate loss of that element when the refuse is ashed at 800°C. It should be noted that there could also have been losses when the ashing was performed in the plasma asher. Elements which showed low ratios were S and K. It is clear that Cl and Br were also lost when ashing at 800°C. Due to spectral interferences from Br and Pb, it was not possible to determine whether Ga, As, and Se were found. It would appear, however, that these elements were not present in significant amounts (compared to the amount of lead, for instance). Germanium was not detected in either sample.

Semiquantitative analysis--There was not enough ash from the plasma ashed sample for a semiquantitative analysis. The high temperature ashed sample was compressed into a planchet and the X-ray spectra taken, along with a standard sample of SRM 1633 trace elements in coal ash. The results of this analysis are included in Table 40.

Energy dispersive X-ray fluorescence was used for the elemental analysis of the coal, bottom ash, collector ash, solid waste, and stack particulates. A molybdenum target X-ray tube was used at 12 kV for low atomic weight elements and at 30 kV for heavier elements. The detection limits in ppm by weight are listed in Table 7. The detection limited for ash samples applies for the bottom ash, collector ash, and solid waste.

TABLE 40. COMPARISON OF HIGH AND LOW TEMPERATURE ASHING OF SOLID WASTE

		Low temp. ash	High temp. ash			Ratio High temp./Low temp.
		Counts	Counts	Concentration		
12 kV	Al	3,605	4,592	~7.8%		1.27
	Si	25,341	28,787	15.1%		1.14
	S	35,710	27,477	3.2%		0.77
	K	83,036	72,192	1.8%		0.87
	Ca	666,744	793,353	12.8%		1.19
	Ti	174,100	215,125	1.58%		1.24
	Cr	5,908	6,[illegible]07	240 ppm		1.07
	Mn	35,789	43,230	2,000 ppm		1.21
	Fe	726,925	754,532	3.14%		1.04
30 Kv	K	12,133	10,688	1.8%		0.88
	Ca	105,453	125,107	12.8%		1.19
	Ti	34,414	39,932	1.58%		1.16
	V	6,383	7,437	< 1,100 ppm	Ti interference	
	Cr	1,937	2,403	240 ppm		1.24
	Mn	15,691	18,213	2,000 ppm		1.16
	Fe	431,129	464,745	3.14%		1.08
	Ni	2,131	2,038	83 ppm		0.96
	Cu	11,114	12,135	420 ppm		1.09
	Zn	228,404	242,250	5,450 ppm		1.06
	Ga	10,455	10,632	< 170 ppm	Pb interference	
	Ge	816	753	< 16 ppm	Zn interference	
	As	2,407	0	< 20 ppm	Pb 7 and Br interference	
	Se	1,758	1,717	< 10 ppm	Pb interference	
	Rb	8,189	7,930	37 ppm		0.97
	Sr	92,717	107,213	423 ppm		1.16
	Pb	267,867	275,405	4,460 ppm		1.03

REFERENCES

1. Standards of Performance for New Stationary Sources. Federal Register, 36(247), Part 11, December 23, 1971.

2. Standards of Performance for New Stationary Sources. Amendments to Reference Methods. Federal Register, 36(111), Part 11, June 8, 1976.

3. Standards of Performance for New Stationary Sources. Federal Register, 38(66), Part 11, April 6, 1973.

4. Carotti, A. A., and E. R. Kaiser. J. for the Air Pollution Control Association. 22(249), 1972.

5. Shannon, L. J., M. P. Schrag, F. I. Honea, and D. Bendersky. St. Louis/Union Electric Refuse Firing Demonstration Air Pollution Test Report. EPA-650/2-74-073, Control Systems Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, August 1974.

6. Fassel, V. A., and R. N. Kniseley. Anal. Chem. Vol. 46, 1110A4, 1155A, 1974.

7. American Society for Testing and Materials, Method D1608.

8. Neker, M. B., and .. W. Jones. In Situ Decomposition Product Isolated from Tenax-GC While Sampling Stack Gases. Anal. Chem. 49(3), March 1977.

9. Rao, A. K. Sampling Line Losses for the Andersen Cascade Impactor. Midwest Research Institute, Kansas City, Missouri, October 8, 1975.

10. Caffe, S. J., and R. W. Serstle, "Emissions from Coal Fired Power Plants: A Comprehensive Summary." U.S. Department of Health, Education, and Welfare, Public Health Service Publication No. 999-AP-35, 1967.

11. Selker, A. P. Program for Reduction of NO_x from Togential Coal Fired Boilers, Phase II. EPA report prepared by Combustion Engineering, Inc. Windsor, Connecticut, EPA 650/2-73-005-a. June 1975.

12. J.A.O.A.C. 53, 761, 1970.

APPENDIX A

STATISTICAL ANALYSIS OF VARIANCE OF RESULTS

The analysis of the variability in the results with respect to the controlled parameters of boiler load and percent RDF in the fuel is given in this section. Standard statistical techniques have been used.[10] In order for the reader to obtain an understanding of this section, a few paragraphs of background, including terminology and explanation, are felt to be essential.

BACKGROUND

Terminology

Variables in experimenter controls are called factors in an experimental design. The number of forms or categories of a factor appearing in an experiment is termed the levels of that factor. A particular combination with one level from each factor is called a treatment. If all possible treatments, or a definite portion of them is of interest, the experiment is called a factorial experiment. It is a complete factorial if all possible treatments are included.

A factor can be quantitative (e.g., different temperatures) or qualitative (e.g , different methods of testing). There is usually no natural order established among different levels of a qualitative factor while such order does exist with levels of a quantitative factor.

In a two factor arrangement, if factor A has n levels, factor B has m levels, there are nm treatments. If repeated measurements (or observations) are made for each treatment there is said to be replication.

If the levels of all quantitative or qualitative factors in an experiment are set at fixed values, one has a so called "fixed model" (or Model I) experiment. This study is a fixed model experiment as all of the levels of each factor are specified as indicated in the following paragraph.

Factors and Levels of Factors for This Study

For this study, it was determined that two major factors could be controlled at various levels. These factors were the load based on steam flow and the amount of RDF based on heat energy input to the boiler. The levels of these factors were chosen to be 60, 80, and 100% nominal load, and 0, 20 and 50% RDF. To obtain sufficient data for statistical analysis, a factorial experimental design with three replications was devised for each boiler as summarized previously in Table 3. Thus, for boiler unit No. 5, the statistical design is a 3 x 3 x 3 full factorial experiment with 27 runs necessary to fill the data matrix of this experiment. In addition, testing of two different size (and design) traveling grate stoker fired boilers (unit Nos. 5 and 6) was accomplished at one load setting (80%) to obtain a relative size comparison for all emission data at a given fixed load. Certainly there are many other secondary and uncontrolled factors that might enter into this study. In order to minimize and possibly eliminate the effect of these secondary and uncontrolled factors it is usually necessary to perform what is called randomization.

Randomization

Randomization is an important requirement of a properly designed experiment so that an unbiased estimate of the error can be obtained. Any unmeasured, unknown, or undesirable influence upon the variation of the responses may contribute to erroneous conclusions related to a set of data. When such influences follow a specific pattern, they are referred to as bias in the data. Biased influences may be caused by uncontrolled differences in time, environment, procedure, etc. These biases can be removed from an experiment if they are recognized during the planning phase and proper procedures taken to control them. Often, however, it is difficult to recognize such biases or, even if they are recognized, to control such biases. Thus, an alternative is to randomize the experiment in such a way that the order of taking data (responses) is predetermined so that each possible response is given an equal opportunity for occurrence. Randomization was not completely possible in these experiments because weather conditions, availability of refuse, and availability of a given boiler unit dictated the order in which tests were scheduled and conducted. However, there was some randomness in each of the above constraints, and this randomness was therefore transferred to the test sequence.

Statistical Model of This Study

In order to test the significance of the different factors controlled in these experiments, established statistical methods were used. For purposes of efficiency and avoidance of incorrect conclusions, such methods were felt to be essential for this study. The technique employed was to test the factors known or assumed to control the variability of a certain measurement (such as

SO_x emissions) according to a prescribed model. The variability of each factor was determined in relation to the variability caused by measurement error (replication). If the factor variability was significantly larger than the measurement-error variability, the factor had a profound effect on the total variability of the measured item. In this way, factors significantly affecting the measured variables can be identified, isolated, and analyzed in greater detail. Inherent to this type of testing is the so called "Analysis of Variance" procedures[1/] for fixed level experimental designs. Such procedures depend on the desired factors with known and stated levels being tested relative to the measured variable (the response). For example, if boiler load and percent RDF in the fuel are tested relative to SO_x emissions, one would have a two factor experiment. One factor would be boiler load with three fixed levels (60, 80, and 100% of rated load), and the other factor would be percent RDF in the fuel with three fixed levels (0, 20, and 50% of fuel heat energy input). For these factors and associated levels of the factors, the data of this study were analyzed according to the following statistical model:

$$Yijk = \mu + Li + Rj + (LR)ij + Eijk$$

where $Yijk$ = measured variable (SO_x or NO_x for example),

μ = true value of the variable being measured with no effect due to any of the following treatments,

Li = effect or treatment caused by the percent load,

Rj = effect or treatment caused by the percent RDF,

$(LR)ij$ = interaction effect of percent load and percent RDF, and

$Eijk$ = measurement error or effect for which one cannot account.

A 95% confidence level was selected for stating conclusions in view of the number of data and the measurement error. A 95% confidence level means that one would be stating conclusions with 95% probability or 20 to 1 odds of having the correct conclusion. Pertinent conclusions at the 95% confidence level are contained in the following sections.

TABULATION OF ANALYSIS OF VARIANCE (ANOV) RESULTS

The ANOV of the data was performed in terms of both emission flow rates (kg/hr) and normalized emission rates (kg/MJ) based on heat energy input. The normalized emission rates were found to be inappropriate in the ANOV procedures because the normalizing parameter (heat energy input) was directly related to both of the controlled parameters in the experiment. This rendered the ANOV procedures ineffective. For this reason, only the ANOV results using emission flow rates (kg/hr) are meaningful. Hence, they are presented and discussed in the following sections of this report. Tables A-1, A-2, A-3, and A-4 summarize the results of the ANOV procedures.

Element flow rates (kg/hr) in the coal, RDF, grate ash, and hopper ash were affected by the boiler load of unit No. 5 as shown in the following table. A positive (+) sign indicates a statistically significant (95% confidence level) increase in the element flow rate with increase in boiler load. A negative (-) sign indicates a statistically significant (95% confidence level) decrease in the element flow rate with increase in boiler load. A blank ( ) represents either no significant effect, or the inability to detect or resolve a significant effect at the 95% confidence level. No analysis for boiler unit No. 6 can be included in this tabulation since only one boiler load (80%) was used for the experiments on this boiler.

Element flow rates (kg/hr) in the coal, RDF, grate ash, and hopper ash were affected by the percent RDF in the fuel input to boiler Nos. 5 and 6 as shown in Table A-2. As before, a (+) indicates a statistically significant (95% confidence level) increase in the element flow rate with increase in RDF. A (-) indicates a statistically significant (95% confidence level) decrease in the element flow rate with increase in RDF. A ( ) represents either no significant effect, or the inability to detect or resolve a significant effect at the 95% confidence level.

COAL ELEMENT FLOW RATES

Analysis of the variability of the element flow rates in the coal show the following:

1. As boiler load increases, the flow rate of most elements in the coal, shown in Table A-1, also increases.

2. As the percent RDF increases for a given boiler load, the flow rate of most elements in the coal shown in Table A-2 decreases. These conclusions are valid for the data from both boiler unit Nos. 5 and 6.

TABLE A-1. ANOV OF ELEMENTS IN COAL, RDF, GRATE ASH, AND HOPPER ASH WITH RESPECT TO BOILER LOAD FOR GIVEN LEVELS OF RDF INPUT

Element	Coal	RDF	Boiler grate ash	Collecter[a] hopper ash
Al	+	+	+	+
As		+	+	+
Ca	+	+	+	+
Cr	+	+	+	+
Cu				+
Ga	+			+
Ge	+	+	+	+
Fe	+	+	+	+
Pb	+			+
Mg	+	+	+	+
Mn	+	+	+	+
Ni				+
P				+
K	+	+	+	+
Rb	+	+	+	+
Se	+		+	+
Si	+	+	+	+
Na		+	+	
Sr		+	+	+
Ti	+	+		+
V		+		+
Zn				+

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[a] Hopper ash elements show an increase from 60 to 80% load but a decrease from 80 to 100% load. The overall or general trend is an increase.

TABLE A-2. ANOV ELEMENTS IN COAL, RDF, GRATE ASH, AND HOPPER ASH WITH RESPECT TO PERCENT RDF INPUT IN THE FUEL FOR GIVEN LEVELS OF BOILER LOAD

Element	Coal 5	Coal 6[b]	RDF 5	RDF 6	Boiler grate ash 5	Boiler grate ash 6	Collecter[a] hopper ash 5	Collecter[a] hopper ash 6
Al	-	-	+	+			+	
As	-	-	+	+	+	+	+	
Ca	-	-	+	+			+	
Cr	-	-	+	+				
Cu		-			+	+	+	
Ga	-	-	+	+	+	+	+	
Ge	-	-	+	+	+		+	
Fe	-	-	+	+			+	
Pb	-	-	+		+	+	+	
Mg	-		+	+	+	+	+	
Mn	-	-	+	+	+		+	
Ni	-							
P		-	+	+	+		+	
K	-	-	+	+				
Rb	-	-	+	+	+		+	
Se	-	-	+	+	+	+		
Si	-	-	+	+	+	+	+	
Na	-		+	+	+	+	+	
Sr	-	-	+	+				
Ti	-	-	+	+	+	+	+	
V	-	-	+	+	+		+	
Zn		-	+	+	+	+	+	

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[a] Hopper ash elements show an increase from 60 to 80% load but a decrease from 80 to 100% load. The overall or general trend in an increase.

[b] 5 and 6 refer to boiler unit Nos. 5 and 6.

TABLE A-3. ANOV OF EFFLUENTS WITH BOILER LOAD FOR GIVEN LEVELS OF RDF IN THE INPUT FUEL

Effluent (emission specie)	Unit no. 5
Particulate Matter (Uncontrolled)[a]	+
Particulate Matter (Controlled)[b]	
Oxides of Nitrogen	
Oxides of Sulfur	+
Aldehydes and Ketones	
Phosphate	
Cyanide	
Chlorides	+
Carbon Dioxide (Orsat)	+
Oxygen (Orsat)	-
Excess Air (Orsat)	-

[a] Uncontrolled particulate emissions were measured between the boiler and the mechanical particulate collector.

[b] The boiler and the mechanical particulate collector controlled particulate emissions were measured in the exhaust stack after the mechanical particulate collector.

TABLE A-4. ANOV WITH PERCENT RDF IN THE INPUT FUEL FOR GIVEN LEVELS OF BOILER LOAD

Effluent (emission specie)	Unit no. 5	Unit no. 6
Particulate Matter (Uncontrolled[a])		
Particulate Matter (Controlled[b]	-	+
Oxides of Nitrogen	-	-
Oxides of Sulfur	-	
Aldehydes and Ketones		
Phosphate		
Cyanide		
Chlorides	+	+
Carbon Dioxide (Orsat)		
Oxygen (Orsat)	+	
Excess Air (Orsat)	+	+

[a] Uncontrolled particulate emissions were measured between the boiler and the mechanical particulate collector.

[b] The boiler and the mechanical particulate collector controlled particulate emissions were measured in the exhaust stack after the mechanical particulate collector.

While these conclusions seem obvious based on "common sense" they are, in fact, based on standard analysis of variance techniques.[1/] Such techniques, if valid, must be consistent with what one knows to be physically true, as they are in this case. It should also be noted that when the variability is large, the ANOV procedures may not detect significant trends in elemental flow rates. In addition, one's intuition or what seems to be common sense is often unreliable. Because of this, the ANOV procedures are felt to be essential for interpretation of data of these experiments.

RDF ELEMENT FLOW RATES

Analysis of the variability of the element flow rates in the RDF show the following:

1. As the boiler load increases for a given percentage of RDF, on a heat energy input basis, the flow rate of most elements in the RDF as shown in Table A-1 increases.

2. As the percent RDF increases for a given boiler load, the flow rate of most elements in the RDF as shown in Table A-2 increases. This conclusion is valid for both boiler unit Nos. 5 and 6.

Again these conclusions from ANOV are consistent with what one knows to be physically true. However, the variability is sufficiently large in some of the elemental constituents of the refuse that the ANOV procedure cannot detect a significant change in elemental flow rate at the 95% confidence level.

ASH ELEMENT FLOW RATES

Grate (Bottom) Ash

Analysis of variability of the element flow rate in the boiler grate ash shows the following:

1. As the boiler load increases for a given percentage of RDF (on a heat energy input basis) the flow rate of most elements, as shown in Table A-1, in the boiler grate ash increase.

2. As the percent RDF increases for a given boiler load, the flow rate of most elements in the boiler grate ash are shown in Table A-2. This is generally true for boiler unit No. 5 and to a lesser extent on boiler unit No. 6. The elements of Ge, Mn, P, Rb, and V on unit No. 6 did not exhibit the increasing trend at the 95% confidence level as found on unit No. 5.

Statistical ANOV has shown a correlation of some elements in the ash with the percent RDF in the fuel. These elements include As, Cu, Ga, Pb, Mg, Mn, Si, Na, V, and Zn.

Hopper (Fly) Ash

Analysis of variability of the element flow rates in the hopper ash show the following:

1. As the boiler load increases for a given percentage of RDF (on a heat energy input basis), the flow rate of many elements, as shown in Table A-1, increases for a 60 to 80% load change, but decreases for an 80 to 100% load change. It is natural to expect only increases in these flow rates as load increases. This effect is most likely to be the result of a significant decrease in particulate collector efficiency for loads above 85 to 90%.

2. As the percent RDF increases for a given boiler load, the flow rate of most elements in the hopper ash follows a similar trend as above. It was noted that a significant interaction effect between percent load and percent RDF existed for most elements on boiler unit No. 5. This would be expected since increases in percent RDF resulted in significant increases in percent excess air (see the section under Effluent Flow Rates on Chlorides), which in turn resulted in increased gas flow in the particulate collector (an effect similar to increasing the load). No significant changes in element flow rates were detected on boiler unit No. 6 with percent RDF at the 80% load condition.

EFFLUENT FLOW RATES

ANOV of the various emission flow rates (kg/hr) from the stack for boiler unit Nos. 5 and 6 were performed with respect to both boiler load and percent RDF in the fuel. Tables A-3 and A-4 summarize these results.

Effluent (emission) flow rates (kg/hr) from boiler unit No. 5 were affected by boiler load as shown in Table A-3. Effluent (emission) flow rates (kg/hr) from the stack serving boiler unit Nos. 5 and 6 were affected by the percentage RDF in the fuel input as shown in Table A-4. A (+) in this table indicates a statistically significant (95% confidence level) increase in the effluent flow rate with increase in boiler load. A (-) indicates a statistically significant (95% confidence level) decrease in effluent flow rate with increase in boiler load. A ( ) represents either no significant effect, or the inability to detect or resolve a significant effect at the 95% confidence level. No analysis for boiler unit No. 6 can be included in this tabulation since only one boiler load (80%) was used for the experiments on this boiler.

Particulates

ANOV of the controlled (stack) particulate emissions with load on unit No. 5, as shown in Table A-3, was inconclusive in that neither an increase nor decrease in particulate flow rate (kg/hr) could be resolved. This means that either a confidence level lower than 95% should be chosen or that more data are needed in order to resolve the effect at the 95% confidence level. Only one load (80%) was used on boiler unit No. 6 so ANOV could not be performed on that data.

The ANOV of the controlled (stack) particulates with percent RDF, as shown in Table A-4, indicates that boiler unit Nos. 5 and 6 have opposite trends. The controlled particulate emissions generally decrease on unit No. 5, but increase on unit No. 6, with an increase in percent RDF for a given boiler load. The reason for the reverse trend on unit No. 6 is believed to be from the additional carry over of "fines" from the input fuel. Boiler unit No. 6 is not much larger physically than unit No. 5, yet the rated loads are 12.5 Mw compared to 7.5 mw. This significant difference in loads means there is also a significant increase in volume flow rate of flue gas and effluents.

Thus, the largest flow rate of combustion or flue gas and particulates will be in the unit No. 6 boiler. Since the two boilers have about the same physical size, unit No. 6, with the higher volume flow, will then have the higher flow velocity of gases and particulates. This, in turn, is believed to be the cause of the additional amounts of fine particles carried through this boiler to the stack.

ANOV of the uncontrolled particulates as sampled before the particulate collectors, shows an increase with boiler load for given levels of RDF input on unit No. 5. No significant increase or decrease was detected on either unit Nos. 5 or 6 as percent RDF increased for given levels of boiler load.

Statistical analysis of variance for the data in megagrams per megajoules units has revealed that some of the chemical elements in the stack particulate effluent correlate well with RDF in the fuel input to the boiler. For example, on boiler unit No. 5 using Iowa coal mixed with RDF, iron, copper, titanium, nickel, zinc, gallium, germanium, selenium, and lead effluents from the stack are significantly related to the RDF input. These elements are based on the analysis of particulate matter caught on the quartz fiber filters in the sampling train. Analysis of the particulates trapped in the impinger water reveal significant correlation of arsenic, selenium, and lead with RDF input to boiler unit No. 5.

For boiler unit No. 6 using a 50/50 mixture of Iowa and Wyoming coal combined with RDF, the significant elements in the stack effluents correlating with RDF, in the input fuel are calcium, chromium, copper, gallium, manganese, selenium, titanium, vanadium, and zinc. These elements are based on the analysis of the particulate matter caught on the quartz fiber filters. Analysis of the particulates trapped in the impinger water reveal no correlation of the elements found with RDF in the input fuel for boiler unit No. 6.

Oxides of Nitrogen (NO_x)

ANOV as shown in Tables A-3 and A-4 indicates a significant decrease in NO_x emission rate with increases in percent RDF for given levels of boiler load. There also was no increase in percent RDF for given levels of boiler load. No increase or decrease in NO_x emission rate could be detected at the 95% confidence level with increases in boiler load. If there is an effect with load, one must either lower the confidence level or obtain more data in order to detect the trend.

The decrease in the NO_x levels indicates either a decreased combustion zone temperature or a decreased resident time in the combustion zone of the appropriate chemical species.

Oxides of Sulfur (SO_x)

ANOV as shown in Tables A-3 and A-4 indicates a significant increase in SO_x emission flow rate (kg/hr) as boiler load increases. A significant decrease occurs as percent RDF is increased for given level of boiler load. These results were conclusive for boiler unit No. 5 and indicate the value of using RDF to decrease the SO_x emissions from such a stationary source of effluent. These results also indicate that one could use a higher sulfur content coal in combination with RDF and still achieve existing SO_x emission standards.

Aldehydes and Ketones (Formaldehyde)

ANOV as shown in Tables A-3 and A-4 indicates neither a detectable increase nor decrease in the emission flow rate of the aldehydes and ketones with variations in either load or percent RDF. If there is an effect with either load or percent RDF, one must either lower the confidence level or obtain more data in order to detect the effect.

The variability in the aldehyde and ketone data was relatively high compared to the other data of this study. One reason for this is that the aldehyde and ketone emissions are quite dependent on the cellulose fiber in the input fuel. Much of such cellulose fiber would be contained in the RDF as wood chips, leaves, and lawn clippings. The amount of these items in the RDF is quite variable on a day-to-day basis. This variability extends to the aldehyde and ketone emissions from the stack which, in turn, masks any trends in the emissions from being detected in the ANOV procedure.

Organic Acids, Cyanide, and Phosphate

ANOV as shown in Tables A-3 and A-4 indicates neither a detectable increase nor decrease in the emission flow rates of both cyanide and phosphate with variation of either load or percent RDF. As stated before, if there is an effect with either load or percent RDF, one must either lower the confidence level or obtain more data in order to detect the effect.

The variation in cyanide emission flow rates were quite high in similar fashion to the aldehydes and ketones emission flow rates. This high variability marks any trends from being detected by the ANOV procedure. The phosphate emissions were usually quite close to the detection limit of the analytical instrumentation and as such may be somewhat unreliable. For this reason the ANOV results for the phosphate may be unreliable.

Chlorides

ANOV of the chloride flow rates, as shown in Table A-3 and A-4, shows a significant increase with increases in both boiler load (for a fixed level of percent RDF in the input fuel) and a percent RDF in the input fuel (for a fixed level of boiler load).

The ANOV also shows that the increase in chlorides flow rate is more predominant with increases in RDF than with increases in boiler load. This would be natural to expect based on the constituents of RDF.

Carbon Dioxide, Oxygen and Excess Air from Orsat Measurements

ANOV of the Orsat data as shown in Tables A-3 and A-4 indicates the following:

1. Carbon dioxide increases significantly, oxygen decreases significantly, and percent excess air decreases significantly with increases in boiler load for given levels of RDF in the input fuel.

2. Oxygen and excess air both increase significantly with increases in the percentage of RDF included in the input fuel for given levels of boiler load. This trend is a direct result of the boiler operators bringing more "overfire" air into the boilers as the percent RDF is increased to the boiler for a given boiler load.

No significant increase or decrease was detected for the carbon dioxide emission with increase in RDF. If there is an effect, one must either lower the confidence level or obtain more data in order to detect the effect.